Incandescent Lamp Engineering

by David R. Dayton

PUBLISHED BY

GENERAL ENGINEERING LABORATORIES

SYLVANIA LIGHTING CENTER

GTE LIGHTING PRODUCTS

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PREFACE

The incandescent lamp is one hundred years old and was considered a mature industry many years ago. Lamp engineering peaked out in the 1930's. Since 1940 lamp engineering has progressed at a rather slow pace except for halogen cycle lamps. The emphasis has been on lamp manufacturing and production.

The purpose of this book is to bring together the lamp engineering knowledge of the past, add recent lamp engineering data and project a higher level of energy conversion.

There are many light sources that are more efficient than incandescent lamps. However, there are many applications where only a small filament light source is suitable.

Incandescent lamps will be with us for many years to come.

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INCANDESCENT LAMP ENGINEERING

1.0 Fundamental Lamp Design Data

The purpose of an incandescent lamp is to produce luminous energy by converting electrical energy to radiant energy. The efficiency of an incandescent lamp as an energy converter is excellent. The problem is that only radiant energy in the visible band is desired. A more specific definition of an incandescent lamp would be a device to convert electrical energy to a selected band of radiation.

The ultimate measure of a lamp design is how much of the input electrical energy (Watts) is converted to luminous energy (lumens). This value is generally expressed as lumens per watt (ℓpw).

Tungsten has long been accepted as the best material for filaments. Therefore, the highest incandescent lamp efficiency (ℓpw) is limited by the inherent properties of tungsten. The important tungsten property for producing light is the intrinsic brilliance as a function of temperature. More simply, a unit area of tungsten heated to a given temperature emits a specific amount of lumens. The following Table 1 shows the intrinsic brilliance of tungsten as a function of temperature.

TABLE 1

T(°K)	Lumens/cm^2
2000	214.0
2100	391
2200	662
2300	1073
2400	1702
2500	2567
2600	3770
2700	5510
2800	7575
2900	10220
3000	13720
3100	18070
3200	23300
3300	29950
3400	37880
3500	47000
3600	57250
3655	63800

The next important tungsten property is the relationship between the electrical energy input to the tungsten and the radiant energy output. Most of the energy is converted to heat (infrared) especially at low filament temperatures. The proportion of visible light increases with the tungsten filament temperature. At lower filament temperatures in the order of 2200°K the radiation is approximately 6% visible light and 94% infrared, and at higher filament temperatures in the order of 2722°K the radiation is approximately 12% visible light and 88% infrared. The higher the filament temperature, the more efficient the conversion of watts to light. The following Table 2 shows the lumens per watt as a function of temperature in vacuum.

TABLE 2

Temperature °K	ℓPW (Forsythe)	ℓPW (Jones and Langmuir)
2400	9.21	9.39
2500	11.46	11.72
2600	14.01	14.34
2700	16.93	17.60
2800	20.03	20.53
2900	23.20	23.64
3000	26.60	27.25
3200	34.5	34.70
3400	43.5	43.20
3655	53.1	53.10

2.0 FILAMENT DESIGN

Filament design can be treated as a function of total energy dissipation or of luminous energy only. Since luminous energy is the desired result, the following filament design discussion will be based on the production of luminous energy.

The energy conversion equation is:

$$\text{Watts} \times \text{lumen/watt} = \text{lumens/cm}^2 \times \text{cm}^2 \qquad (1)$$

Table 1 and Table II show that the ℓpw value and intrinsic brightness value are directly related to the tungsten temperature. The energy equation shows that at a given temperature, watts are directly related to the effective surface area of the filament. For example,

the theorical surface area of a 25 watt-9.35 ℓpw(filament temperature approximately 2400°K) would be

$$25 \times 9.35 = 1702 \times A\,cm^2$$

Effective Surface Area = 0.137338 cm^2.

THE EFFECTIVE SURFACE AREA IS THE SAME WHETHER THE FILAMENT IS STRAIGHT WIRE, SINGLE COIL, OR COIL COILED.

For a straight filament, the energy conversion equation (1) can be re-written.

$$\text{Watt} \times \ell pw = \text{lumens}/cm^2 \times \pi d \ell \qquad (2)$$

The next fundamental property of tungsten of interest is the resistivity of tungsten as a function of temperature. Table 3 shows the values according to Jones and Langmuir and also Forsythe and Worthing.

TABLE III

T°K	Resistivity(Jones & Langmuir)	Resistivity(Forsythe & Worthing
	micro ohm/cm^3	micro ohm/cm^3
2400	70.39	73.6
2500	73.91	77.3
2600	77.49	81.0
2700	81.04	84.7
2800	84.70	88.5
2900	88.33	92.3
3000	92.04	96.2
3100	95.76	
3200	99.54	103.8
3300	103.3	
3400	107.2	112
3500	111.1	
3600	115.0	
3655	117.1	121

The differences in the work of Langmuir and Forsyth are about 4% and not significant.

The resistance of an electrically heated mass can be calculated from basic data.

$$R = \rho \times \frac{l}{s}$$

where ℓ = length, s = cross section and ρ is specific resistance.

$$R\ (\text{ohm}) = \frac{\rho \times 4 \times \ell}{\pi d^2} \qquad (3)$$

$$\text{Ohm's Law} \quad I = \frac{E}{R} \qquad (4)$$

$$\text{Watts} = IE = I^2R \qquad (5)$$

By substitution, the basic energy conversion equation (2) can be rewritten.

$$I^2R \times \ell pw = \text{lumen/cm}^2 \times \pi d(R\pi d^2/4\ ) \qquad (6)$$

The wire diameter for a straight wire filament can now be calculated. For example: calculate the wire diameter (d) for a 150 watt, 120 volt, 17.6 ℓpw, straight wire tungsten filament for a vacuum lamp.

From Table 2, ℓpw indicates a temperature of 2700°K
From Table 3, the resistivity is 81.04 micro ohms.
From Table 1, the instrinsic brightness is 5510 lumens/cm^2

$$\text{Watts} = IE \qquad I = \frac{150}{120} = 1.25 \text{ amps}$$

$$\text{Ohm's Law} \quad I = \frac{E}{R} \qquad R = \frac{120}{1.25} = 96 \text{ ohms.}$$

$$I^2R \times \ell pw = \text{lumens/cm}^2 \times \pi d \left(\frac{R\pi d^2}{4\rho}\right)$$

$$1.25^2 \times 96 \times 17.6 = 5510 \times \pi \times d \left[\frac{96 \times \pi \times d^2}{4 \times 81.04 \times 10^{-6}}\right]$$

$$2640\ d^3 = 1.6105 \times 10^{10}$$
$$d^3 = 1.639242 \times 10^{-7}$$
$$d = 5.47285 \times 10^{-3} \text{cm}$$

From the energy conversion (1) the effective surface area for the 150 watt lamp in example can be calculated.

Watt $\times$ ℓpw = Intrinsic Brightness $\times$ Effective Surface Area
150 $\times$ 17.6 = 5510 $\times$ Effective Surface Area
Effective Surface Area = 0.479129 cm^2
Effective Surface Area of a round wire = $\pi d\ell$

$$\pi d \ell = 0.479129$$

$$.00547285 \quad \pi \ell = 0.479129$$

$$\ell = 27.866 \text{ cm}$$

or from Equation (3) $R = \dfrac{\rho \times 4 \times \ell}{\pi d^2}$

$$96 = \frac{81.04 \times 4 \times \ell \times 10^{-6}}{\pi(.0054728)^2}$$

$$\ell = 27.866 \text{ cm}$$

The theoritical straight wire tungsten filament is a piece of round wire .00547285 cm in diameter and 27.866 cm long. In practice, extra would have to be added for clamping and overhang.

By cancellation in Equation (6), it can be shown that at any filament temperature d^3 varies as I^2,

OR d varies as $I^{\frac{2}{3}}$

Since tungsten wire is usually measured by the weight of 200 mm and expressed in mg per 200 mm (wire weight)

Wire Weight = 1.943 (wire diameter in mils)^2

it can now be defined that wire weight in mg/200 mm varies as $I^{\frac{4}{3}}$.

By going back to Equation (6) and substituting for d instead of ℓ and IE instead of I^2R, it would be concluded that ℓ varies at the cube root of I and directly as E

$$\ell \text{ varies as } I^{\frac{1}{3}}E.$$

NOTE: When currents are very low, the exponents for current must be modified. This problem will be discussed in detail in section 2.4 on Filament Design.

2.1 Effect of Filament Operating Temperature on Wire Weight

The foregoing data on calculating wire diameter or wire weight required using tabulated tungsten properties at selected temperatures. Energy conversion equation (6) requires three properties

of tungsten at the required temperature. Variables which are all related to one variable in this case, temperature, are related to each other.

$$I^2R \times \ell pw = \text{lumens/cm}^2 \times \frac{\pi^2 R^2 d^3}{4 \times \rho} \qquad (6)$$

Intrinsic Brightness(lumens/cm^2) varies as $\ell pw^{1.8779}$

Resistivity varies as $\ell pw^{0.22685}$

Equation (6) can now be rewritten

$$I^2R \times \ell pw = \frac{\ell pw^{1.8779} \times \pi^2 \times R \times d^3}{\ell pw^{0.22685}}$$

and condensed to

$$d^3 = \frac{I^2}{\ell pw^{0.651}}$$

$$d = \frac{I^{\frac{2}{3}}}{\ell pw^{0.217}} \times \text{a constant} \qquad (7)$$

$$\text{Wire Weight varies as } \frac{I^{\frac{4}{3}} \times \text{a Constant}}{\ell pw^{0.434}} \qquad (8)$$

Equation (6) can be rewritten for substitution of (d) instead of ℓ

$$\text{Watt} \times \ell pw = \text{lumen/cm}^2 \times \pi d \ell$$

$$\text{Watt} \times \ell pw = \text{lumen/cm}^2 \times \pi \ell \left(\frac{\rho \times 4 \times \ell}{R}\right)^{\frac{1}{2}}$$

$$\text{Watt} \times \ell pw = \text{lumen/cm}^2 \times \frac{\pi \times \ell \times \rho^{\frac{1}{2}} \times 4^{\frac{1}{2}} \times \ell^{\frac{1}{2}}}{R^{\frac{1}{2}} \times \pi^{\frac{1}{2}}}$$

$$IE \times \ell pw = \frac{\ell pw^{1.8779} \times \pi^{\frac{1}{2}} \times \ell^{\frac{3}{2}} \times 2 \quad \ell pw^{0.113425}}{\left(\frac{E}{I}\right)^{\frac{1}{2}}}$$

$$I^{\frac{1}{2}}\,E^{\frac{3}{2}} = \ell pw^{0.9913}\;\ell^{\frac{3}{2}} \times 2 \times \pi^{\frac{1}{2}}$$

$$\ell = \frac{I^{\frac{1}{2}\times\frac{2}{3}} \times E^{\frac{3}{2}\times\frac{2}{3}}}{\ell pw^{\left(\frac{0.9913}{1.5}\right)}} \times \text{a Constant}$$

$$\ell = \frac{I^{\frac{1}{3}}\,E}{\ell pw^{0.661}} \times \text{A Constant} \qquad (9)$$

The constant needed for the general equations (8) and (9) can be roughly calculated from Langmuir's data. The following table shows a relationship between filament temperatures and current.

TABLE IV

Temp °K	Amps/cm$^{\frac{3}{2}}$
2400	1422
2500	1526
2600	1632
2700	1741
2800	1849
2900	1961
3000	2072
3100	2187
3200	2301
3300	2418
3400	2534
3500	2657
3655	2838

To use the data in Table IV, the following formula is applicable.

$$\frac{A}{d^{\frac{3}{2}}} = \text{Amps/cm}^{\frac{3}{2}} \text{ at Desired Temperature from Table IV.}$$

where A = the lamp current in Amps.

For example, A = 1.25, Temperature is 2700°K and ℓpw is 17.6

$$\frac{1.25}{d^{\frac{3}{2}}} = 1741$$

$$d^{\frac{3}{2}} = 0.000717978$$

$$d = 0.008018\text{cm}$$

Wire Weight = 20.15 mg/200mm

$$\text{Wire weight} = \frac{I^{\frac{4}{3}} \times C}{\ell pw^{.434}}$$

$$20.15 = \frac{1.25^{\frac{4}{3}} \times C}{17.6^{.434}}$$

C = 51.95

$$\text{Wire Weight} = \frac{51.95\ I^{\frac{4}{3}}}{\ell pw^{.434}} \qquad (10)$$

$$R = \frac{\rho \times 4 \times \ell}{\pi d^2}$$

From Watts $\times\ \ell pw$ = lumen/cm^2 $\times\ \pi d\ell$

$$150 \times 17.6 = 5510 \times \pi d\ell$$

$$\pi d\ell = 0.4791288$$
$$d = .008018$$
$$\ell = 19.021 \text{ cm}$$

$$19.021 = \frac{(1.25)^{\frac{1}{3}} \times 120 \times C}{17.6^{0.661}}$$

C = .9795 when ℓ is in cm or

C = 9.795 when ℓ is expressed in mm

$$\ell(\text{mm}) = \frac{9.795\ I^{\frac{1}{3}}\ E}{\ell pw^{0.661}} \qquad (11)$$

In the real world, additional length would be required for legs, clamping, overhang, supports, etc.

At this point, general formulae for wire weight (8) and wire length (9) have been developed which cut across Table I, II, III and IV and can be used to calculate wire weight and wire length from basic lamp data.

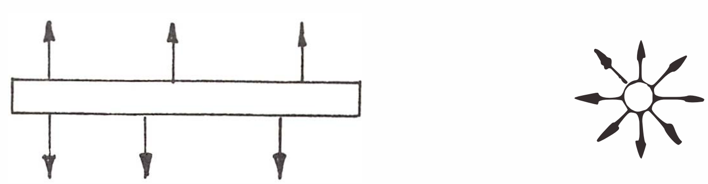
From Equation (6) the calculated wire diameter is 5.47285×10^{-3} cm and length is 27.866 cm. From Langmuir table, the wire diameter is 8.018×10^{-3} cm and length is 19.021 cm.

The reason for the difference in calculated wire diameter (d) from Equation (6) and from Langmuir's Table IV is energy conversion Equation (6) is theoretical data and Table IV is empherical data from actual experiments. The difference is 0.008018 vs 0.00547 or approximately 46% which is not unreasonable for this type of research and the equipment available at that time (65 years ago).

The calculations in this section were based on a 150 watt, 120 volt lamp. When the lamp current is less than one amp, which includes just about all vacuum lamps, some correction is required due to the ratio of wire cross section to wire circumference. This problem will be discussed in detail further on.

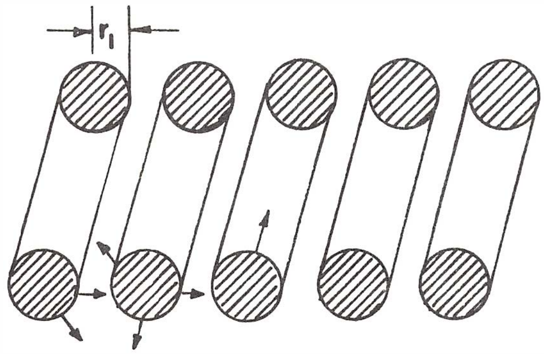
2.2 Single Coiled Filaments

In the case of straight wire filaments, the radiation is from the entire surface.



It should be noted that for straight wire filaments there is only one design that will yield the correct watts and lumens at a given voltage.

When the straight wire filament is coiled, some of the radiation is blocked.



The shadowing of one turn by another results in two effects. The effective surface area of filament is reduced and the blocked radiation is absorbed by the next turn and results in raising the temperature of that turn. The net effect is if a correct straight wire filament was coiled, the filament temperature would rise, current would drop, life would drop and lumens would probably drop depending on how hot the filament got.

The correct coiled filament will have the same effective area as the straight wire filament at the same temperature as the straight wire filament. The problem is to find the effective surface area as a function of coil winding pitch.

The effective area of a coil wound at 100% pitch (turns touching) can be calculated and is 33 1/3%. The effective area of coils wound at 125%, 150%, 200%, etc. can be determined by making large scale drawings and ray tracing. The assumption is made that the wire is perfectly round, that all radiation is normal to the surface of the wire and that radiation which is directed at another part of the coil is 100% adsorbed by the receptor. These assumptions are not totally valid but are true to a relatively constant degree.

The ray tracing the calculation of the effective area of a coil made to various winding pitches and mondrel ratios is found to be described by a logarithmic curve.

$$\text{Effective Area} = 1.05119 + 0.30086 \ \ell n \ \text{Pitch} \ \% \qquad (12)$$

For example: Find the effective area of a coil wound at 150% pitch.

$$\text{Effective Area Factor} = -1.05119 + 0.30086 \ \ell n \ 150$$
$$Af = -1.05119 + 1.5075$$
$$Af = 0.4563$$
$$Af = 45.63\%$$

This means that to get the same radiating area, the surface of the wire is going to have to be increased by the reciprocal of 0.4563 or 2.19 times. Since wire weight is the design parameter for filament design, the relationship of surface area to cross-sectional area must be determined. The total surface area of a piece of wire is $\pi d\ell$, but doubling the surface area would not double the diameter. It is also known that since

$R = \dfrac{\rho \times 4 \times \ell}{\pi d^2}$ that ℓ/d^2 is fixed for a certain resistivity and lamp resistance balance.

Suppose $\pi d\ell = 0.13271\text{cm}^2$ $\qquad \dfrac{\ell}{d^2} = 19,957,178$

$$d^3 = 2.1 \times 10^{-9}$$
$$d_1 = 1.28396 \times 10^{-3}$$

If $\pi d\ell$ is doubled, $\pi d\ell = 0.26542\text{cm}^2$

$$d^3 = 4.2 \times 10^{-9}$$
$$d_2 = 1.61768$$

Wire weight is proportional to d^2 and therefore

$$\frac{d_2^{\,2}}{d_1^{\,2}} = 2 \text{ (double Surface Area)}$$

$$\left(\frac{2.6169}{1.64855}\right)^x = 2$$

$$1.587^x = 2$$

$$x = 1.5$$

Therefore, d^2 or wire weight varies with surface area to the 1.5 power or area$^{2/3}$ varies with wire weight.

The general formula for calculating wire weight for a coiled filament becomes

$$\text{Wire Weight} = \frac{\text{Surface Area Factor }(Af)^{\frac{2}{3}} \times I^{\frac{4}{3}} \times C}{\ell pw^{.434}} \qquad (13)$$

Where "C" is a constant with a value of approximately 51.95.

As already stated, any change in wire weight requires an equal change in wire length in order to keep lamp resistance and hot resistivity of the tungsten wire constant. Therefore:

$$\ell = \frac{\text{Surface Area Factor }(Af)^{\frac{2}{3}} \times I^{\frac{1}{3}} \times E \times C}{\ell pw^{0.661}} \qquad (14)$$

Where "C" is a constant with a value of approximately 9.8 and will vary depending on mount type.

At this point, a coiled filament can be calculated. For example: 150 Watt, 120 volt, 17.6 ℓpw, C-9 mount, single coil wound at 125% pitch

$$\text{Wire Weight} = \frac{51.95\left[\frac{1}{(-1.05119 + 0.30086\ \ell n\ 125)}\right]^{\frac{2}{3}} \times (1.25)^{\frac{4}{3}}}{(17.6)^{0.434}}$$

$$\text{Wire Weight} = \frac{51.95 \times 1.83756 \times 1.3465}{3.47178}$$

Wire Weight = 37.02 mg/200

Effective Filament Length =

$$\frac{9.8 \left[\frac{1}{(-1.05119 + 0.30086\ \ln 125)}\right]^{\frac{2}{3}} \times 120 \times (1.25)^{\frac{1}{3}}}{(17.6)^{0.661}}$$

$$\text{Effective Length} = \frac{9.8 \times 1.83756 \times 120 \times 1.0772}{6.657}$$

Effective Length = 349.7 mm

2.3 Coiled Coil Filaments

For coiled coil lamp filament design, the secondary coiling is considered to have some general effect as primary coiling. This is not quite true, but nevertheless has the same relationship and is in error to a constant multiplier.

The general formula for a coiled coil filament is:

$$\text{Wire Weight} = \frac{(Af_p)^{\frac{2}{3}} \times (Af_s)^{\frac{2}{3}} \times I^{\frac{4}{3}} \times C}{\ell pw^{0.434}} \qquad (15)$$

$$\text{Wire Length} = \frac{(Af_p)^{\frac{2}{3}} \times (Af_s)^{\frac{2}{3}} \times I^{\frac{1}{3}} \times E \times C}{\ell pw^{0.661}} \qquad (16)$$

Coiled coils are not generally used in vacuum lamps. However, Equations (15) and (16) are also basic for gas filled lamps and will be discussed in more detail further on.

2.4 Low Current Vacuum Lamps

Most vacuum lamps are low current lamps. At amphere values of less than one amp, some correction is required to calculate wire weight and wire length for any filament type. The problem relates to the ratio of mass to surface area of the filament wire. When the ratio gets too big, it is like a steam radiator with too many fins. The radiator is too cool because the fins can dissipate the heat at a greater rate than the steam pipe can supply the heat. The radiator would increase in temperature if some of the fins (surface area) were eliminated.

Lamp engineers have been aware of the problem for years. When coiled filaments were designed, the lamp designer used Langmuir data in Table IV and soon found that the calculation worked quite well for a coiled filament even though the data were based on a straight wire filament. They concluded that coiling the wire reduced the effective area by a factor of 2. The following table shows the necessary change in wire weight as a function of lamp current.

Lamp Current	Wire Weight Reduction %	Wire Diameter Reduction %
0.0583	47.7	21.6
0.0652	45.6	20.6
0.1087	35.7	16.5
0.125	33.1	15.4
0.2083	24.1	11.4
0.5000	10.0	4.9
0.8333	2.5	1.3
1.000	-0-	-0-

For filament design, the correction can be made by modifying the current exponent as follows:

$$\text{Wire Weight} = \frac{52\ (Af)^{\frac{2}{3}}\ I^{1.471}}{\ell pw^{.434}} \qquad (17)$$

$$\text{Wire Length} = \frac{9.8\ (Af)^{\frac{2}{3}}\ I^{0.368}\ E}{\ell pw^{0.661}} \qquad (18)$$

At this point, the wire weight and wire length for an actual lamp can be designed. For example, 25 Watt, 125 volt, 92 ℓpw, C-9 mount, single coil wound at 156% pitch. The 9.2 ℓpw is the measured ℓpw, the actual ℓpw of the bare filament without losses to leads, bulb glass absorbtion, etc. is greater than the measured ℓpw by approximately 10%. This problem will be discussed in detail further on. For this example a 1.10 ℓpw multiplier will be used. The length constant for a C-9 filament has been found to be 18.32

$$\text{Wire Weight} = \frac{.52\ Af^{\frac{2}{3}}\ I^{1.471}}{\ell pw^{0.434}}$$

$$\text{Wire Weight} = \frac{52 \times 1.6587 \times 0.09372}{2.7305}$$

$$\text{Wire Weight} = 2.96\text{mg}$$

$$\text{Wire Length} = \frac{18.32\ Af^{\frac{2}{3}}\ I^{0.368}\ E}{\ell pw^{0.661}}$$

$$\text{Wire Length} = \frac{18.32 \times 1.6587 \times 0.5531 \times 125}{4.62}$$

$$\text{Wire Length} = 454.94\text{ mm}$$

For reference, the actual wire weight of a typical 25 Watt, 125 volt, 9.2 ℓpw lamp is 2.6 mg and total filament length is 580 mm. At this point, the ℓpw exponents are traceable to basic theory. Fine tuning by computer results in the final formulas for single coil vacuum lamps.

2.4.1 General Vacuum Lamp Filament Design Formulae

Lamp Current Less Than One (1) Amp.

$$\text{Wire Weight} = \frac{50.59\ Af^{\frac{2}{3}}\ I^{1.471}}{(1.07\ \ell pw)^{0.429}} \tag{19}$$

$$\text{Wire Length} = \frac{18.32\ Af^{\frac{2}{3}}\ I^{0.368}\ E}{(1.07\ \ell pw)^{0.54}} \tag{20}$$

Lamp Current Greater Than One (1) Amp.

$$\text{Wire Weight} = \frac{50.59\ Af^{\frac{2}{3}}\ I^{\frac{4}{3}}}{(1.07\ \ell pw)^{0.429}} \tag{21}$$

$$\text{Wire Length} = \frac{18.32\ Af^{\frac{2}{3}}\ I^{\frac{1}{3}}\ E}{(1.07\ \ell pw)^{0.54}} \tag{22}$$

When the wire weight and wire length are calculated with the final formulae, the results are:

Wire Weight = 2.948 mg.

Wire Length = 601 mg.

Another example would be a 15 Watt, 230 volt, 8 ℓpw, vacuum lamp with a C-9 mount and single coil wound at 156% pitch.

$$\text{Wire Weight} = \frac{50.59 \times 1.6587 \times 0.018076}{2.54}$$

Wire Weight = 0.59717 mg/200

$$\text{Wire Length} = \frac{18.32 \times 1.6587 \times 0.36617 \times 230}{3.236}$$

Wire Length = 790.8 mm.

Typical wire weight and wire length for this lamp is approximately 0.65 mg by 810 mm long.

Further fine tuning would be possible with carefully made lamps and accurate photometry.

It should be noted that the reference data for typical lamps is not necessarily good design data. It just happens to be an existing filament design and not indicated to be a correct or better design. There are an infinite number of filament designs with coiled wire which will have the same watts, current, volts, and lumens. The variable is lamp life. The design which has the required lumens at lowest filament temperature is the optimum design for that pitch and wire size. This problem and how to approach the optimum design will be discussed in more detail further on.

2.5 Gas Filled Lamps

When the vacuum in a lamp is replaced by an inert gas, the filament is cooled, the luminous output decreases and the lamp current increases. Gas losses result from the flow of filling gases in a convection stream past the filament, rising to the top of the bulb and circulating down the sides. The gas carries heat away from the filament and transfers the heat to the bulb glass and lamp base. Vacuum lamps lose heat only by radiation. Gas filled lamps lose heat by radiation plus the gas loss energy. The amount of heat lost to the gas fill varies with wire mass to surface ratio and also filament geometry and orientation. At the same time, the gas fill lowers the evaporation rate of tungsten by about 100 orders of magnitude.

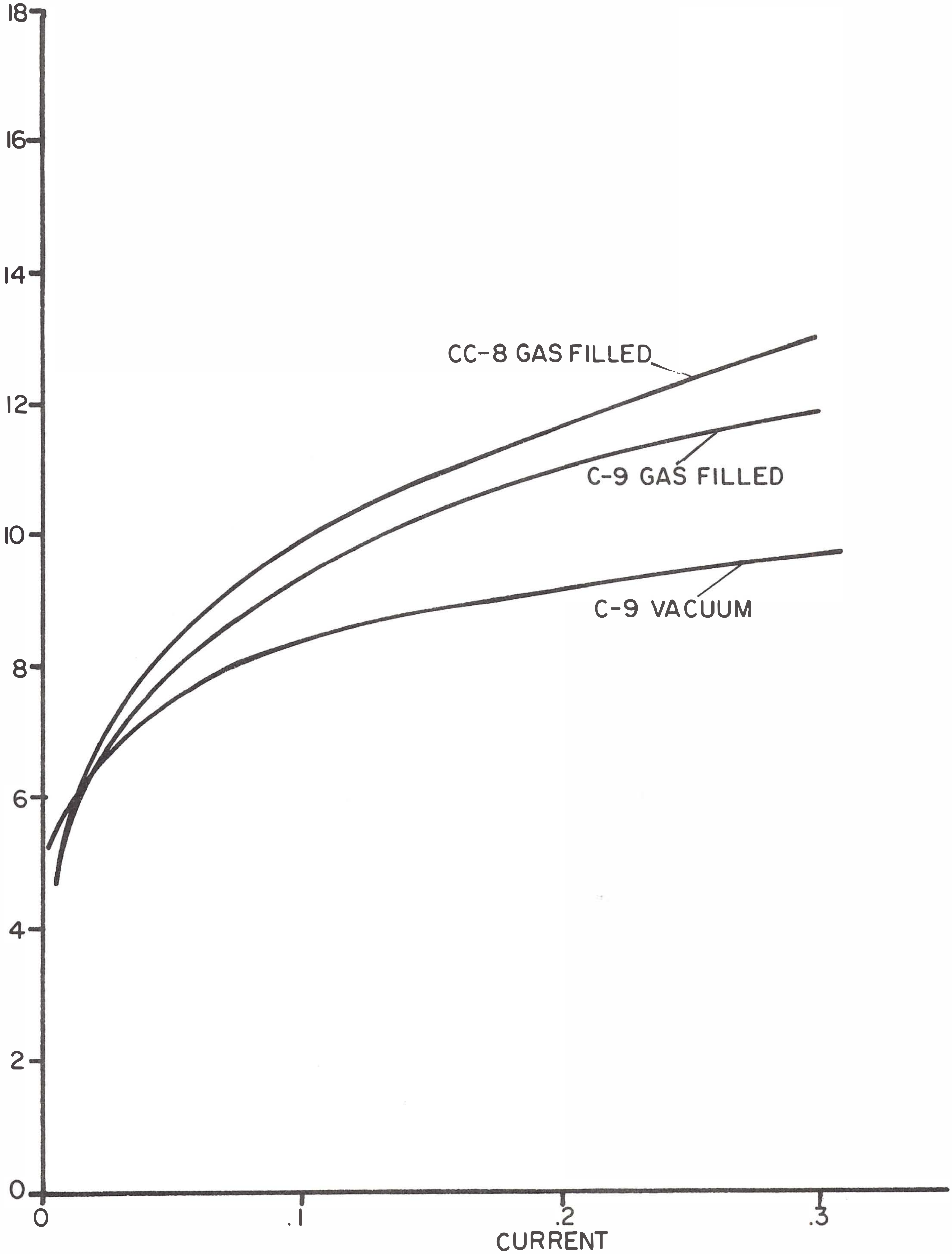
The gas loss energy results in a decrease in filament mass for a lamp with the same characteristics as a vacuum lamp.

The design for a single coil lamp gas filled with 25 Watt, 125 volt and 9.2 ℓpw made with same % pitch and mandrel ratios as the vacuum lamp would be as follows:

- Wire weight - 1.811 mg/200 mm.
- Wire diameter - .00245 cm.
- Wire length - 44.5 cm.

The following Table V shows the difference between a vacuum lamp and gas filled lamp with same input-output characteristics.

25 Watt - 125 volt - 9.2 ℓpw



18
16
14
12
10
8
6
4
2
0
CC-8 GAS FILLED
C-9 GAS FILLED
C-9 VACUUM
0
.1
.2
.3
CURRENT

TABLE V

	Vacuum Lamp	Gas Filled Lamp
Wire Weight	2.96 mg/200 mm	1.811 mg/200 mm.
Wire Diameter	0.00313 cm	0.00245 cm
Wire Length	61.2 cm	44.5 cm
Total Surface Area	9.6018 cm^2	0.3425 cm^2
Effective Area	0.3623 cm^2	0.2062 cm^2
Filament Weight	9.0576 mg	4.0295 mg

Analysis of the data in Table V shows that there is not only energy lost to the gas fill but also the filament must run at a higher temperature in a gas filled lamp. Since both lamps have same lumen output (230 lumens), the lumens emitted per cm^2 of filament area can be calculated. The intrinsic brightness value varies with temperature.

Vacuum Lamp

Lamp lumens - Intrinsic brightness x area

230 = Lumen/cm^2 x 0.3623

Lumens/cm^2 = 634.8

Indicated wire temperature = 2191°K

Gas Filled Lamp

Lamp lumens - Intrinsic brightness x area

230 - Lumen/cm^2 x 0.2062

Lumen/cm^2 - 1115.8

Indicated wire temperature - 2308°K.

The vacuum lamp looses energy by radiation only except for end losses. The watts radiated are a function of wire temperature and effective surface area of the coil. The gas filled lamp looses energy by radiation, end losses and gas losses.

Vacuum Lamp Watts = Watts Light + Watts Heat + End Losses (Watts)
Watts Heat (J) varies with Intrinsic Brightness (D)

D = 634.8 Lumen/cm^2 J = 37.5 Watts/cm^2

Watts radiated as Heat = J x Effective Area

= 37.5 x 0.3623

= 13.59 Watts

Gas Filled Lamp Watts = Watts Light + Watts Heat (IR + Gas Loss) + End Losses

D = 1115.8 Lumen/cm^2 J = 47.93 Watts/cm^2

Watts Radiated as Heat = J x Effective Area

= 47.93 x 0.2062

= 9.883

Gas Loss Watts = 13.59 - 9.883 = 3.707 Watts

$$\% \text{ Gas Loss} = \frac{3.707}{13.59} = 27\%$$

The net result of gas filling is a smaller filament, a higher filament temperature, a much lower tungsten evaporation rate and a longer life by about a factor of three compared to a similar vacuum lamp. As the wattage or current of a lamp decreases, the difference in filament temperatures increases and finally a point is reached where the life of a vacuum lamp and gas filled lamp are equal.

The balance then is, where for equal life and lumens, the bigger filament, lower temperature and higher evaporation rate of a vacuum lamp balances the smaller filament, higher temperature and lower tungsten evaporation rate of a gas filled lamp.

The reduction in evaporation rate due to the gas fill is the controlling factor. Vacuum lamps have a present maximum efficiency of about 10 ℓpw. In this area, a reduction in evaporation rate of 100X means a filament wire in a gas filled lamp could run at a temperature about 300°K higher than a filament in a vacuum lamp and have equal life.

In terms of gas loss, the 300°K would result in an intrinsic brightness variation of 323% or an effective surface area reduction of 323% in the gas filled lamp. Since watts radiated in vacuum lamp must equal watts

radiated in gas filled lamp plus gas loss watts, the watts radiated/cm^2 in a vacuum lamp is approximately 57.7 watts/cm^2 and watts ratiated/cm^2 in gas filled lamp is 99.6 watts/cm^2 it follows that

$$57.7 \times 1 = \text{Vacuum lamp radiation loss } (2400°K)$$

$$99.6 \times \frac{1}{3.23} = \text{Gas filled lamp radiation loss } (2700°K)$$

$$\frac{57.7 - 30.76}{57.7} = 46.68\% \text{ gas loss.}$$

The calculation shows that a gas filled lamp could have almost 50% of its input energy lost to the gas fill and still have equal life and lumens.

The following table shows the gas loss % of equal vacuum and gas filled lamps. All lamps have single coil C-9 filaments.

Watts	Gas Loss %
25	27
40	24
100	22

The maximum allowable gas loss of 46% for single coils will not be reached until wattage drops below 25 watts or .208 amps.

Figure 1 is a plot of existing vacuum lamps as a function of current and ℓpw. The curves for C-9 gas filled lamps and CC-8 gas filled lamps are extensions of curves of actual lamps. All lamps are same design life (1000 hours). The curves show a cross-over at about .05 amps (6 watts).

It is not meaningful to exactly define the cross-over point, because in the real world, the fragility of the filament may be the controlling factor. However, some reasonable conclusions can be reached.

1. The crossover point for vacuum vs gas filled lamps is between 6 watts (.05 amps) and 25 watts (.208 amps).

2. For single coils, the crossover point is about 18 watts (.15 amps).

3. For coil coil lamps, the crossover point is about 12 watts (.10 amps).

2.5.1 General Gas Filled Lamp Filament Design Formulae

The general formulae for filament design for gas filled lamps are fundamentally the same as for vacuum lamps.

$$\text{Wire Weight} = \frac{Af^{\frac{2}{3}} \; I^{\frac{4}{3}} \; C}{\ell pw^{.429}}$$

$$\text{Wire Length} = \frac{Af^{\frac{2}{3}} \; I^{\frac{1}{3}} \; E \; C}{\ell pw^{0.54}}$$

For lamps obove 1 amp, only the constants are modified. For C-9 mount in conventional A-line bulb, the constant is 31.69 for wire weight and 13.69 for wire length. This means that the wire weight is $\frac{31.69}{50.59}$ or 37.4% less in an equal gas filled lamp than in a vacuum lamp and by the same token, the wire is 25.3% shorter. The fact that the wire weight and wire length reduction are not equal means that for the same lamp resistance that the wire is running at a higher temperature in the gas filled lamp.

For lamps with currents less than 1 amp. the gas loss increases for the same reason that the vacuum lamps needed correction. That is, the surface area of the wire to the wire mass ratio increases as the wire diameter decreases and the net result is that heat is radiated <u>and</u> conducted from the outside of the wire at a greater rate than the supply. Again like a steam radiator with too many fins. The energy is being transferred but the radiator is only warm instead of hot. The correction is to reduce the radiating and conducting surface and raise the temperature and in this case, light output from the radiator.

Current < 1 amp.

$$\text{Wire Weight} = \frac{Af^{\frac{2}{3}} \; I^{1.471} \; C}{\ell pw^{0.429}} \qquad C = 31.69$$

$$\text{Wire Length} = \frac{Af^{\frac{2}{3}} \; I^{0.368} \; E \; C}{\ell pw^{0.54}} \qquad C = 13.69$$

The constants are the same as for the high current lamps.

Example (Current less than one (1) amp).

60 Watt, 125 volt, 12.38 ℓpw, gas filled, C-9 mount, single coil wound at 131% pitch. Increase ℓpw 10% for correction of bulb losses.

$$\text{Wire Weight} = \frac{Af^{\frac{2}{3}} \; I^{1.470} \times 31.69}{\ell pw^{0.429}}$$

$$\text{Wire Weight} = \frac{\left[\frac{1}{(-1.05119 + 0.30086 \, \ell n 131)}\right]^{\frac{2}{3}} \times \left(\frac{60}{125}\right)^{1.470} \times 31.69}{13.84^{0.429}}$$

$$\text{Wire Weight} = \frac{1.7957 \times 0.33996 \times 31.69}{3.08} = 6.28 \text{ mg}$$

$$\text{Wire Length} = \frac{Af^{\frac{2}{3}} \; I^{0.368} \; E \times 13.69}{\ell pw^{0.54}}$$

$$\text{Wire Length} = \frac{1.7957 \times 0.7633 \times 125 \times 13.69}{4.133}$$

$$\text{Wire Length} = 567.58 \text{ mm}$$

A typical lamp of these characteristics has a wire weight of 6.25 mg and wire length of 529 mm.

Example (current greater than one (1) amp).

200 Watt, 125 volt, 16 ℓpw, gas filled, C-9 mount, single coil would at 130% pitch. Increase ℓpw 10% for correction of bulb losses.

$$\text{Wire Weight} = \frac{Af^{\frac{2}{3}} \times I^{\frac{4}{3}} \times 31.69}{\ell pw^{0.1429}}$$

$$\text{Wire Weight} = \frac{1.80 \times \left(\frac{200}{125}\right)^{\frac{4}{3}} \times 31.69}{17.6^{0.429}}$$

$$\text{Wire Weight} = \frac{1.80 \times 1.8714 \times 31.69}{3.422}$$

$$\text{Wire Weight} = 31.2 \text{ mg}$$

$$\text{Wire Length} = \frac{Af^{\frac{2}{3}} \; I^{\frac{1}{3}} \; E \times 13.69}{\ell pw^{0.54}}$$

$$\text{Wire Length} = \frac{1.8 \times 1.1696 \times 125 \times 13.69}{4.705}$$

$$\text{Wire Length} = 765.68 \text{ mm}$$

A typical lamp of these characteristics has a wire weight of 31.5 mg and wire length of 780 mm.

At this point, it is obvious that for same mount configuration and bulb type, that the formulae for calculating the wire weight and wire length are identical except for the constants. Or to put it another way, for an equal gas filled lamp compared to a vacuum lamp, the wire weight is reduced 37.4% and wire length reduced 25.3%. In terms of surface area, this is a 40% reduction and means a 40% increase in intrinsic brightness for equal lumens.

The gas loss varies with mount type, bulb type, lamp burning position, filament temperatures, filament geometry, etc. These problems will be discussed in more detail further on.

At this stage, there are a few important points.

1. Coiling results in a heavier and longer wire than a straight wire filament. Lamp life will be longer with the coiled filament due to the larger mass filament. Lamp life will be discussed in detail further on.
2. The general formula for design of like filaments is fundamentally the same for vacuum and gas filled lamps. Only the constant is modified.

Lamp Current Less than one (1) Amp.

$$\text{Wire Weight} = \frac{Af^{\frac{2}{3}} \; I^{1.470} \; C}{\ell pw^{0.429}}$$

C = 50.59 for Vacuum Lamps

C = 31.69 for Gas Filled Lamps

$$\text{Wire Length} = \frac{Af^{\frac{2}{3}} \; I^{0.368} \; E \; C}{\ell pw^{0.54}}$$

C = 18.32 for Vacuum Lamps

C = 13.69 for Gas Filled Lamps

Lamp Current Greater than one (1) Amp.

$$\text{Wire Weight} = \frac{Af^{\frac{2}{3}} \; I^{\frac{4}{3}} \; C}{\ell pw^{0.429}}$$

C = 50.59 for Vacuum Lamps

C = 31.69 for Gas Filled Lamps

$$\text{Wire Length} = \frac{Af^{\frac{2}{3}} \; I^{\frac{1}{3}} \; E \; C}{\ell pw^{0.54}}$$

C = 18.32 for Vacuum Lamps

C = 13.69 for Gas Filled Lamps

2.6 Measured Lumens vs Indicated Lumens

Incandescent lamps are rated on the basis of measured lumens and wattage. Incandescent lamps must be designed on the basis of theoretical lumens or indicated lumens.

The difference between measured lumens and indicated lumens depends upon several variables. The indicated lumens and lumens per watt is a function of the fundamental properties of tungsten at the filament temperature. The measured lumens and lumens per watt equals indicated lumens and ℓpw minus losses. The losses are generally as follows:

1. End Loss. This loss is energy conducted to leads and also lumens blocked by leads. In addition, there is also an I^2R drop in the leads.
2. Support Loss. This loss is energy conducted from filament to support and results in cool spot on filament and some lumen blockage.
3. Bulb Loss. Bulb glass is not 100% transparent and absorbs some of the radiation and also has some first surface reflection. Various bulb treatments, such as frosted, painted, smoked, reflectorized, etc. have varying losses.
4. Base Loss. This loss is due to radiation interrupted by the the base. The smaller the base and the further the base location from the filament, the lower the base loss.
5. Mount Geometry. The loss from a no support CC-8 is the least and a multisupport single coil like a rough service mount, has the highest losses.
6. Gas Loss. This loss is due to heat conducted from the filament by the fill gas. The heat is conducted and convected to the bulb wall. The amount of gas loss varies as a function of filament temperature, mount geometry, types of fill gas, bulb size, filament design and several other variables..

For general lighting service lamps, the historic losses are as follows:

1. End losses	-	1.2 - 1.9%
2. Support Losses	-	2% each support
3. Bulb Loss	-	1 - 5%
4. Base Loss	-	4 - 10%
5. Gas Loss	-	6 - 30%

2.6.1 Effect of Fill Gas Properties on Gas Loss

The amount of gas loss depends on mass of filament and type and pressure of fill gas. By switching from $88Ar12N_2$ fill to 100% Kr in an 80 watt, 120 volt, 20 ℓpw lamp, the ℓpw would increase due

to reduced conduction from the filament. The amount of change is a function of the conductivity of the different gases. At an average gas temperature of 2000°K the conductivity is as follows:

Gas	Thermal Conduction (Watts/cm)
Nitrogen	1.291
Argon	0.811
Krypton	0.459
Xenon	0.271

88/12 Thermal Conduction = .88(.459) + .12(1.291) = 0.5588 Watts/cm

100% Kr Thermal Conduction = 0.459 Watts/cm^2

For this lamp type the change in ℓpw varies with gas thermal conduction to the 1/3 power.

$$\left(\frac{.5588}{.459}\right)^{\frac{1}{3}} = 1.068$$

or the ℓpw would increase to 6.8% going from 88/12 Kr/N_2 to 100% Kr.

The exponent varies with lamp current and has not been worked out for a general formula at this time.

In general, the higher the molecular weight of the fill gas, the less the gas loss and the higher the ℓpw. The filament design must be modified when the fill gas is changed. The formulae can be compensated by modifying the ℓpw multiplier up for heavier fill gases and down for lighter fill gases.

2.6.2 Effect of Fill Gas Pressure on Gas Loss

For GLS lamps, the fill pressure for all lamps is usually about one (1) atmosphere. For halogen lamps, the fill pressure is as high as 10 atmospheres. The higher the pressure of the fill gas, the higher the gas loss and results in lower ℓpw and higher lamp current. The loss in ℓpw has been found to be proportional to the

fill gas pressure to the -0.030 power. For example, if the fill pressure in a 20 ℓpw lamp at one atmosphere was increased to 3 atmospheres and to 6 atmospheres, the ℓpw would drop as follows:

$$20 \times P^{-0.03}$$

$$20 \times 3^{-0.03} = 19.35 \text{ ℓpw}$$

$$20 \times 6^{-0.03} = 18.95 \text{ ℓpw}$$

The exponents seem to be independent of fill gas mix and lamp current. The following table indicates the necessary ℓpw compensation as a function of fill pressure.

Fill Pressure	ℓpw	ℓpw Multiplier for Filament Design Modification
1	100%	
2	0.9794	1.021
3	0.9676	1.033
4	0.9593	1.042
5	0.9529	1.049
6	0.9477	1.055
7	0.9433	1.060
8	0.9395	1.064
9	0.9362	1.068
10	0.9332	1.072

With this kind of variation in losses, there is no general way to treat measured lumens vs indicated lumens. Various lamp groups must be treated separately. The common denominator for all lamps is filament temperature. The following table shows the measured and indicated ℓpw for several lamp types as a function of filament temperature.

Lamp	Bulb Type	Mount Type	Filament Temp °K	Measured ℓpw	Indicated ℓpw	ℓpw Ratio
60W/120V	A-19	CC-8NS	2814	14.66	20.9	1.43
75W/120V	A-19	CC-8NS	2836	16.24	21.59	1.33
100W/120V	A-19	CC-8NS	2860	17.21	22.35	1.30
150W/120V	A-21	CC-8	2909	18.73	23.98	1.28
1095	S-8	C-6	2535	6.7	12.57	1.87
1093	S-8	C-6	2770	11.14	18.77	1.68
1067	G-6	C-2R	2522	5.0	12.23	2.45
1143	RP-11	C-2R	2907	15.04	23.55	1.57
1183	RP-11	C-2V	2969	12.41	26.01	2.09
1209	B-6	C-6	2882	11.34	22.62	1.99
1217	G-6	C-2V	2348	3.56	8.6	2.41
1289	G-6	C-2R	2584	7.29	13.52	1.85
ELH	T-3	CC-8	2406	29.74	44.36	1.41

The data indicates lamp wattage, mount type, bulb type and filament temperature are major variables. NS - no support

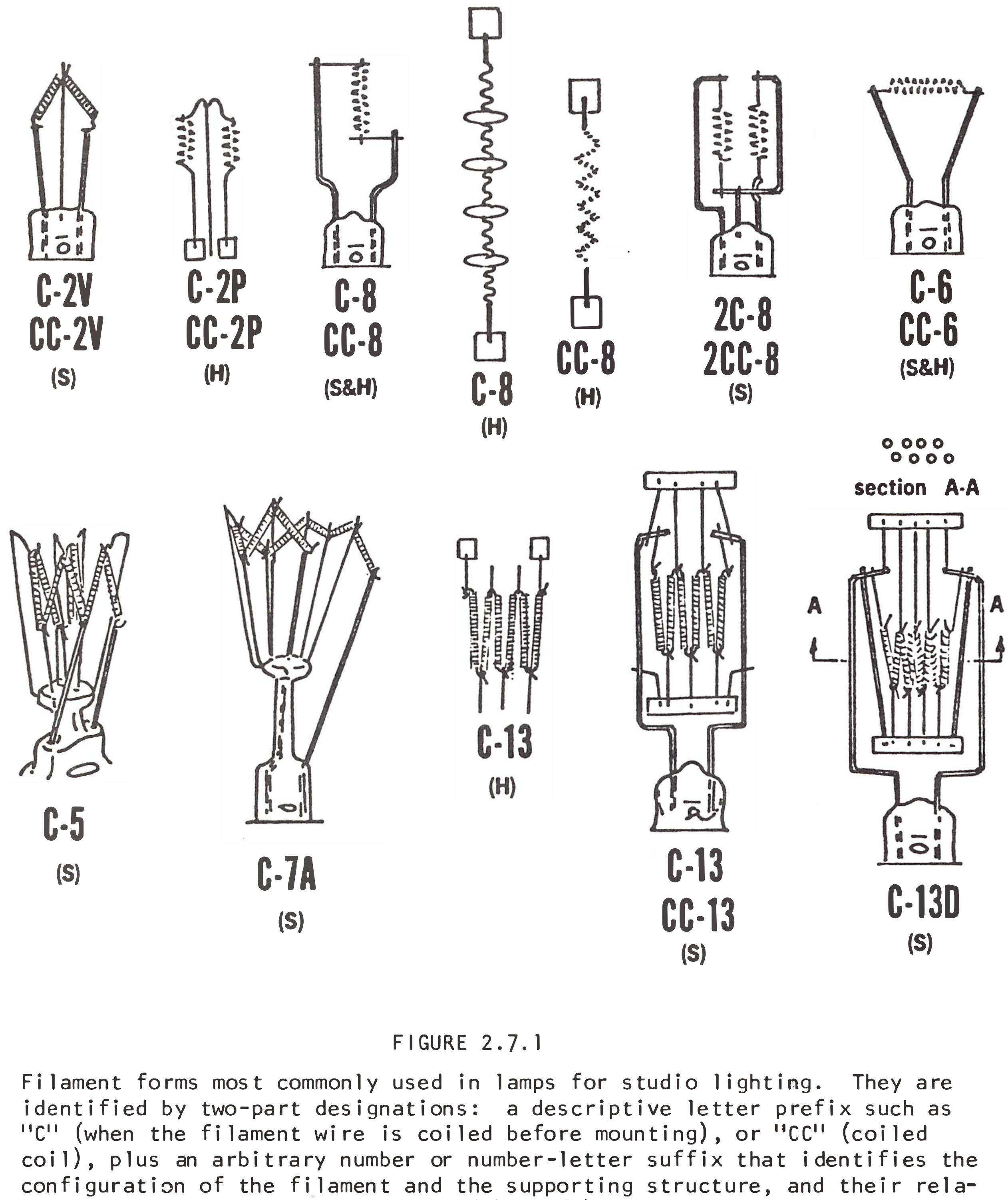


FIGURE 2.7.1

Filament forms most commonly used in lamps for studio lighting. They are identified by two-part designations: a descriptive letter prefix such as "C" (when the filament wire is coiled before mounting), or "CC" (coiled coil), plus an arbitrary number or number-letter suffix that identifies the configuration of the filament and the supporting structure, and their relation to the lamp axis. The letter (S) or (H) indicate whether the particular filament form is primarily associated with standard (S) or halogen-cycle (H) lamps. Proportions of filament and details of mount structures in specific lamps may vary considerably from the illustrations.

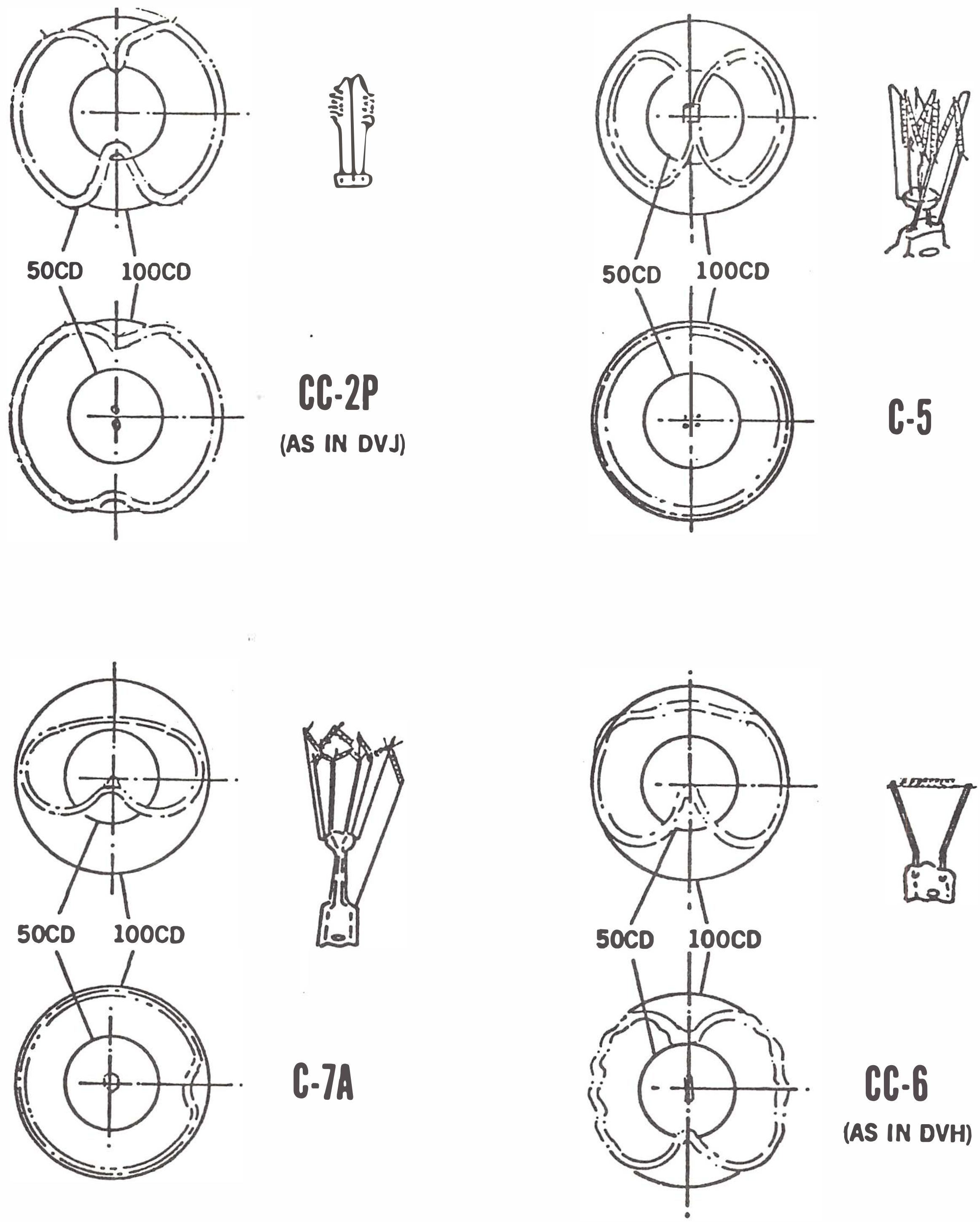


FIGURE 2.7.2

Generalized polar distribution of candlepower for several of the filament types of Figure 2.7.1. Circular reference lines indicate intensity values of 50 and 100 candelas per 1000 lumens of total emitted light. Angles of measurement are in plane of paper when filament is oriented as indicated in the center of each polar plot. Curves are of typical lamps with each filament form; specific lamp types may have considerably different distributions.

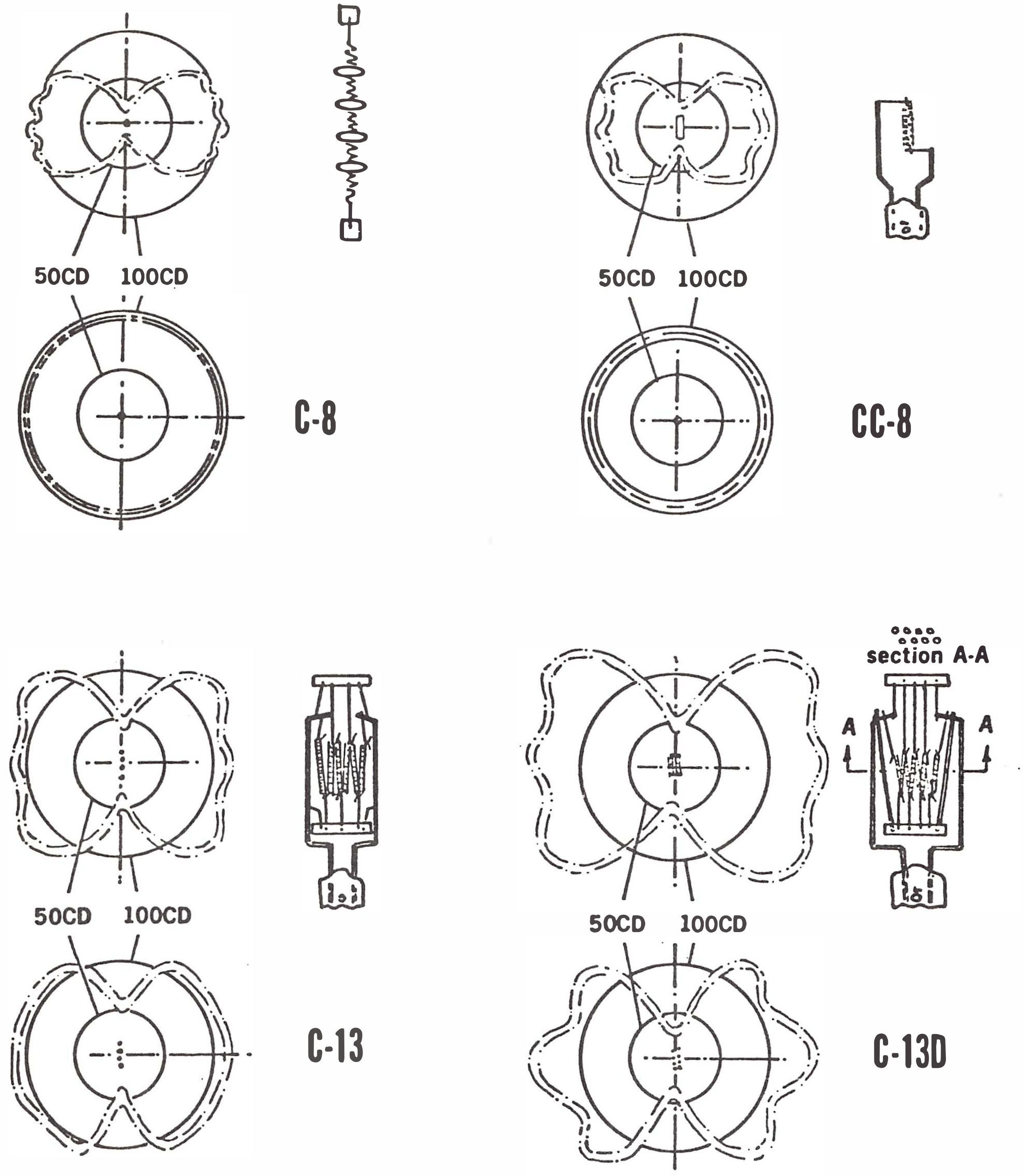


FIGURE 2.7.3
Generalized polar distribution of candlepower for several of the filament types of Figure 2.7.1. Circular reference lined indicate intensity values of 50 and 100 candelas per 1000 lumens of total emitted light. Angles of measurement are in plane of paper when filament is oriented as indicated in the center of each polar plot. Curves are of typical lamps with each filament form; specific lamp types may have considerably different distributions.

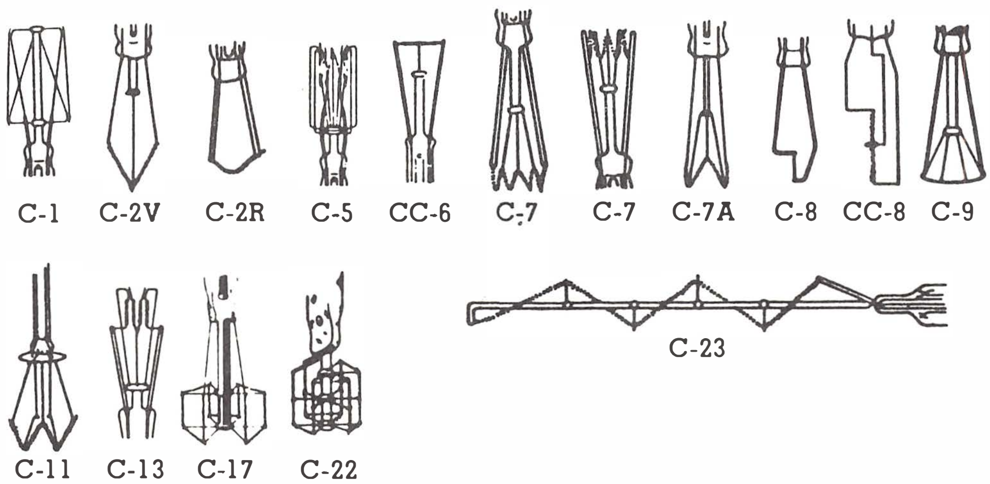


TABLE VI

VARIOUS INCANDESCENT LAMP FILAMENTS

Filament Designation	Description	Typical Lamp Using This Filament
C-1	Fairly long coiled filament, well supported.	15W, S-11, 75V, Train
C-2V	Fairly short coiled filament which requires one support.	6000 lumen, PS-40, Street Series
C-2R (Rounded)	Short filament, slightly rounded, requiring no supports.	30 volt, A-21 Street Railway
C-5	Concentrated filament for small light sources.	500W, G-40 Spot or Flood
C-6	Short coiled filament requiring few or no supports.	50W, A-21, 6 volt
CC-6	Short coiled-coil filament requiring few supports.	60W, A-19
C-7	Fairly long filament supported at top for base up burning.	10,000 lumen, PS-40, base up 20 amp., St. Series
C-7	Fairly long filament supported at bottom for base down burning.	10,000 lumen, PS-40, base down 20 amp., St. Series
C-7A	Long filament supported top and bottom for universal burning.	500W, PS-40, 230 volt
C-8	Coiled filament mounted along axis of bulb. May be elongated as in lumiline lamps.	25W, T-10, Showcase
CC-8	Short coiled-coil filament along axis of bulbs.	100W, A-19
C-9	Filament of average length, well supported. Semi-circular. Also used for vibration service.	25W, A-19
C-11	Concentrated filament of some length. Well supported. "M" — shaped.	250W, G-30, Infrared
C-13	Monoplane filament, high concentrated for peojection equipment.	500W, T-20, Spotlight
C-17	Long filament requiring more than average number of supports.	100W, A-21, Rough Service
C-22	Long filament with extra supports for resistance to physical shock.	50W, A-19, Rough Service
C-23	Coiled filament mounted along axis of bulb and alternated along the length.	40W, T-8, Showcase

2.8 Filament Design Formulae

In the real world, filament design must be based on measured lumens because that is the criteria on which the lamps are rated. On this basis, common types of incandescent lamps are broken down into categories where the input in Watts, Volts and measured ℓpw plus pitch selections for single coiled and double coiled filaments.

2.8.1 Miniature and Sub-miniature Vacuum Lamps

Mount types C-6, C-2V, C-2R or C-2F

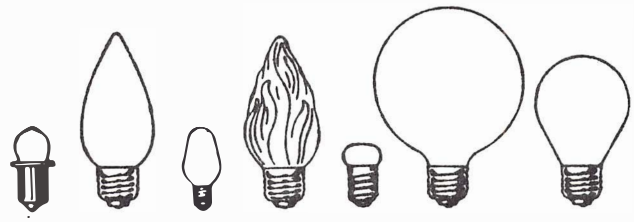
$$W_w = \frac{19.83\ A\ I^{1.239}}{\ell pw^{.2588}}$$

Where A = Area Factor
I = Lamp Current in AMPS
E = Design Voltage
ℓpw = measured ℓpw

$$L = \frac{13.22\ A\ I^{\frac{1}{3}}\ E}{\ell pw^{.5}}$$

NOTE: $\frac{MSCP\ (4\pi)}{IE} = \ell pw$

2.8.2 Large (A-Line) Vacuum Lamps



Large (A-Line) Vacuum Lamps

Mount Type C-9

Less than 1 AMP Lamp Current

$$W_w = \frac{50.59\ A\ I^{1.47}}{(1.069\ \ell pw)^{.429}}$$

$$L = \frac{18.32\ A\ E\ I^{0.368}}{(1.069\ \ell pw)^{.54}}$$

More than 1 AMP Lamp Current

$$W_w = \frac{50.59\ A\ I^{1.333}}{(1.069\ \ell pw)^{.429}}$$

$$L = \frac{18.32\ A\ E\ I^{\frac{1}{3}}}{(1.069\ \ell pw)^{.54}}$$

Where A = Area factor

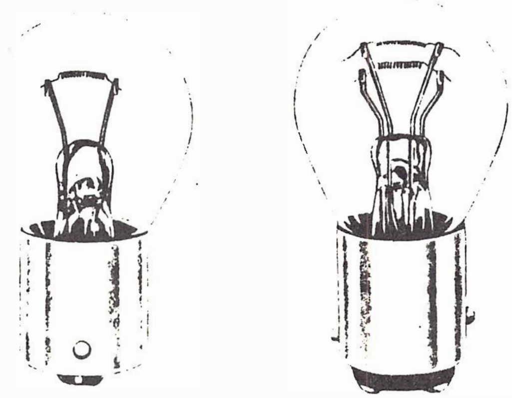
E = Design Voltage

I = Lamp Current in AMPS

ℓpw = Measured ℓpw

NOTE: $\ell pw = \dfrac{MSCP\ (4\pi)}{I\ E}$

2.8.3 Miniature Gas Filled Lamps



Mount Type C-6, C-2R, or C-2V

Less than 1 AMP Lamp Current

$$W_w = \frac{31.36\ A\ I^{1.769}}{\ell pw^{.429}}$$

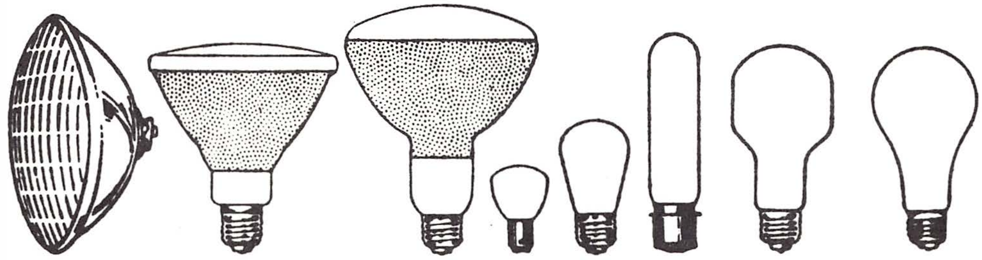
$$L = \frac{12.20\ A\ I^{0.442} E}{\ell pw^{.54}}$$

Greater than 1 AMP Lamp Current

$$W_w = \frac{31.36\ A\ I^{1.333}}{\ell pw^{.429}}$$

$$L = \frac{12.20\ A\ I^{\frac{1}{3}}\ E}{\ell pw^{.54}}$$

2.8.4 Large Gas Filled Lamps



Mount Type C-9

Less than 1 AMP Lamp Current

$$W_w = \frac{31.69\ A\ I^{1.471}}{\ell pw^{.429}}$$

$$L = \frac{13.69\ A\ E\ I^{.368}}{\ell pw^{.54}}$$

Greater Than 1 AMP Lamp Current

$$W_w = \frac{31.69\ A\ I^{1.333}}{\ell pw^{.429}}$$

$$L = \frac{13.69\ A\ E\ I^{\frac{1}{3}}}{\ell pw^{.54'}}$$

Mount Type CC-8

Less than 1 AMP Lamp Current

$$W_w = \frac{27.25\ A\ B\ I^{1.424}}{(1.1\ \ell pw)^{.495}}$$

$$L = \frac{9.863\ A\ B\ E\ I^{.348}}{(1.1\ \ell pw)^{.54}}$$

Greater than 1 AMP Lamp Current

$$W_w = \frac{27.25\ A\ B\ I^{1.3633}}{(1.1\ \ell pw)^{.495}}$$

$$L = \frac{9.863\ A\ B\ E\ I^{\frac{1}{3}}}{(1.1\ \ell pw)^{.54}}$$

Mount Type CC-9 (European Type)

Less than 1 AMP Lamp Current

$$W_w = \frac{27.52\ A\ B\ I^{1.424}}{(1.07\ \ell pw)^{.495}}$$

$$L = \frac{9.863\ A\ B\ E\ I^{.348}}{(1.07\ \ell pw)^{.54}}$$

Greater than 1 AMP Lamp Current

$$W_w = \frac{27.52\ A\ B\ I^{1.3633}}{(1.07\ \ell pw)^{.495}}$$

$$L = \frac{9.863\ A\ B\ E\ I^{1/3}}{(1.07\ \ell pw)^{.54}}$$

Where A = Primary Area Factor

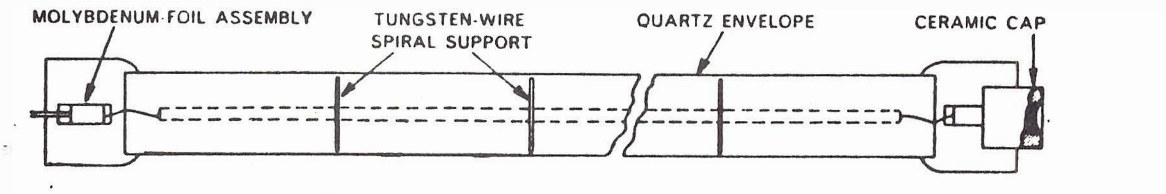
B = Secondary Area Factor

E = Design Volts

I = Lamp Current

ℓpw = Measured ℓpw

2.8.5 Linear Halogen Lamps



$$W_w = \frac{36.75\ A\ I^{\frac{4}{3}}}{\ell pw^{0.472}}$$

$$TFL = \frac{22.50\ A\ E\ I^{\frac{1}{3}}}{\ell pw^{0.7}}$$

2.8.6 Segmented Halogen Lamps

$$W_w = \frac{36.75\ A\ I^{4/3}}{\ell pw^{0.472}}$$

$$\text{Effective Wire Length} = \frac{19.00\ A\ E\ I^{1/3}}{\ell pw^{0.7}}$$

2.8.7 Halogen Lamps - Single Coil with C-6 Mount

$$W_w = \frac{31.36\ A\ I^{\frac{4}{3}}}{\ell pw^{0.495}}$$

$$\text{Effective Wire Length} = \frac{8.67\ A\ I^{\frac{1}{3}}\ E}{\ell pw^{0.54}}$$

TFL = Effective Wire Length + Legs

2.8.8 Halogen Lamp - Short Life - Coiled Coil - CC-8

$$W_w = \frac{26.91\ A\ B\ I^{\frac{1}{3}}}{1.2\ \ell pw^{0.495}}$$

$$\text{Effective Wire Length} = \frac{9.86\ A\ B\ I^{\frac{1}{3}}}{1.2\ \ell pw^{0.54}}$$

TFL = Effective Wire Length + Overhand and Legs

TABLE VI

2.9 AREA FACTOR FOR COILED AND COILED COIL FILAMENTS

$$\text{Pitch \%} = \frac{100}{\text{TPI} \times (\text{d in inches})} \quad \text{or} \quad \frac{100}{\text{TP mm (d in mm)}}$$

TPI = Turns per inch

TPmm = Turns per millimeter

d = Wire diameter

Pitch %	A (Primary or Single Coil) Area Factor	B (Secondary) Area Factor
125	1.844	
126	1.837	
127	1.830	
128	1.822	
129	1.815	
130	1.808	
131	1.801	
132	1.795	
133	1.788	
134	1.781	
135	1.775	
136	1.769	
137	1.763	
138	1.756	
139	1.750	
140	1.745	
141	1.739	
142	1.733	
143	1.727	
144	1.722	
145	1.716	
146	1.711	
147	1.706	
148	1.700	
149	1.695	
150	1.690	1.690
151	1.685	1.685
152	1.680	1.680
153	1.675	1.675
154	1.670	1.670
155	1.666	1.666

Note: Pitch % value is pitch as mounted including any stretch at mounting. For Coiled Coils, consider all stretch to take place in secondary coiling.

TABLE VI (continued)

Pitch %	A (Primary or Single Coil) Area Factor	B (Secondary) Area Factor
156	1.661	1.661
157	1.656	1.656
158	1.652	1.652
159	1.647	1.647
160	1.643	1.643
161	1.639	1.639
162	1.634	1.634
163	1.630	1.630
164	1.626	1.626
165	1.622	1.622
166	1.617	1.617
167	1.613	1.613
168	1.609	1.609
169	1.605	1.605
170	1.601	1.601
171	1.598	1.598
172	1.594	1.594
173	1.590	1.590
174	1.586	1.586
175	1.583	1.583
176	1.579	1.579
177	1.575	1.575
178	1.572	1.572
179	1.568	1.568
180	1.565	1.565
200	1.502	1.502
225	1.439	1.439
250	1.388	1.388
275	1.346	1.346
INF or Straight Wire	1.000	1.000

3.0 Filament Correction Technique

It is often desirable to make small corrections in filaments to cope with a range of wire size (usually $\pm$ 3%) or to correct life or ratings.

CHANGE WIRE WEIGHT AND WIRE LENGTH

Convert change in watts and ℓpw to change in wire weight and wire length.

$$\text{New Wire Weight} = \text{Old Wire Weight} \left[\frac{\text{Watts Desired}}{\text{Present Watts}}\right]^{a} \left[\frac{\text{Present } \ell\text{pw}}{\ell\text{pw Desired}}\right]^{b}$$

$$\text{New Wire Length} = \text{Old Wire Length} \left[\frac{\text{Watts Desired}}{\text{Present Watts}}\right]^{c} \left[\frac{\text{Present } \ell\text{pw}}{\ell\text{pw Desired}}\right]^{d}$$

3.1 Exponents for Various Lamp Types

The following exponents can be used:

	For Micro and Subminiature Vacuum Lamps
a	1.239
b	0.259
c	0.333
d	0.500

	For Single Coil Miniature and GLS Vacuum Lamps with C-6 or C-9 Mounts	
	Less than 1 Amp	Greater than 1 Amp
a	1.470	1.333
b	0.429	0.429
c	0.368	0.333
d	0.540	0.540

	For Single Coil Gas-Filled Miniature Lamps C-6, C-2R, or C-2V	
	Less than 1 Amp	Greater than 1 Amp
a	1.769	1.333
b	0.429	0.429
c	0.442	0.333
d	0.540	0.540

	For Single Coil Gas-Filled Large Lamps with C-9 Mount	
	Less than 1 Amp	Greater than 1 Amp
a	1.471	1.333
b	0.429	0.429
c	0.368	0.333
d	0.540	0.540

	For Coiled Coil Gas-Filled Lamps With CC-8 or CC-9 (European) Mounts	
	Less than 1 Amp	Greater than 1 Amp
a	1.424	1.363
b	0.495	0.495
c	0.348	0.333
d	0.540	0.540

3.2 COIL CORRECTION WITH ORIGINAL WIRE SIZE AND CHANGE PITCH AND WIRE LENGTH.

The wire weight is directly related to coil pitch. Therefore, a change in the coil pitch can be used instead of a wire weight change. To use this procedure, perform the following steps:

1. Convert required change in watts and ℓpw to a change in wire weight and wire length using proper exponent.
2. Divide original wire size by new wire size; this is the change factor (CF).
3. Determine old area factor A or B from Table VI and multiply by the change factor (CF). The product will be the new area factor A or B.
4. Determine the Pitch % for new area factor from Table VI. This will be the new coil winding Pitch % with original wire size.
5. Miltiply original wire length by (CF).
6. Adjust filament manufacturing data to reflect new winding pitch and wire length.
7. Make new filaments and test in lamps.

3.3 <u>Coil Corrections - Rule of Thumb</u>

<u>Less than 1 Amp Lamp Current</u>

+1% Watts = +1.474% W_w, + 0.3665% Filament Length

+1% ℓpw = -0.4260% W_w, - 0.5359% Filament Length

+ 1% W_w = + 0.8455% Watts, + 0.5783% ℓpw

+ 1% Filament Length = -0.6720% Watts, - 2.3257% ℓpw

+ 1% Pitch = +0.07% Watts, -0.30% ℓpw

<u>Greater than 1 Amp Lamp Current</u>

+ 1% Watts = +1.3355% W_w +0.3324% Filament Length

+ 1% ℓpw = -0.4260% W_w, -0.5459% Filament Length

+ 1% W_w = +0.9335% Watts, +0.5790% ℓpw

+ 1% Filament Length = -0.7412% Watts, -2.3259% ℓpw

+ 1% Pitch = 0.07% Watts, -0.30% ℓpw

<u>General - All Lamps</u>

+ 1% Pitch = +0.07 Watts, -0.27% ℓpw	(Vacuum Lamps)
+ 1% Pitch = +0.07 Watts, -0.30% ℓpw	(Gas-filled Lamps)
+1% TPI = -0.11% Watts, +0.43% ℓpw	(Vacuum Lamps)
+1% TPI = -0.11% Watts, +0.48% ℓpw	(Gas-filled Lamps)

+ 1% ℓpw = 7% life

If an error made in mounting the coil is such that the lighted filament length is affected, the following relationships occur:

1% L.T.S. (Lead Tip Spacing) = -(10 - 12%) Life
+ 0.5% Current
+ 0.5% Wattage
+ (1.5 - 1.75%) ℓpw
+ (2 - 2 1/2%) Lumens

4.0 Optimized Coil Design Procedure

As already stated, when the filament wire is coiled, there are an infinite number of designs which will yield the same watts and measured ℓpw at the same rated volts. However, when the pitch is fixed, there is an optimum design that will have the longest lamp life. The optimum coil design will be the one that has the desired lumens at the lowest coil temperature. The fundamental energy conversion equation

$$\text{Watts} \times \ell\text{pw} = \ell\text{pw/cm}^2 \times \text{Effective Coil Surface Area}$$

is satisfied by any equal ratio of intrinsic brightness and coil surface area. However, since the current is fixed, there will finally be some wire size that cannot be heated to a high enough temperature and some surface area that radiates too much heat and limits the intrinsic brightness. The coil temperature is a critical life factor because the evaporation rate of tungsten varies as the 30th power of temperature so that even a 5°K temperature rise results in approximately a 5% change in life or a 50°K temperature rise will reduce lamp life by 50%.

The temperature of a coil is not uniform from "Clamp to Clamp" and, therefore, the optimum coil cannot be calculated directly. However, the optimum design can be found empherically and the general filament design formula for that lamp type can be modified so that all future designs will be optimized.

The optimum coil design can be found empherically as follows:

1. Design coil from basic formula for that lamp type and lamp operating current. Note that the input for pitch is mounted pitch % including stretch if any at mounting.
2. Use same design regarding pitch, mandrel, etc., but use 5% larger wire size and 5% longer length. Repeat with 10% larger wire weight and 10% longer length.
3. Manufacture several lamps of each design. Use low tolerance wire ($\pm$ 1 1/2%) if available.
4. Age at least 5 test lamps of each design and carefully photometer and measure current, lumens and filament temperature at center section of coil.

The measured watts and ℓpw may get out of line, but the data should indicate a direction to work in that can be corrected for desired watts and ℓpw at lowest coil temperature. When the final design is developed, it should only be necessary to modify the constants in the basic wire weight and wire length formulae to tune the formulae for optimized coil design.

When wire weight and pitch are fixed, the only variable is filament wire length. Since:

+1% Filament Wire Length = -0.6720% Watts, -2.3257% ℓpw (< 1 Amp)
-1% Filament Wire Length = +0.6720% Watts, +2.3257% ℓpw

+1% Filament Wire Length = -0.7412% Watts, -2.3259% ℓpw (>1 Amp)
-1% Filament Wire Length = +0.7412% Watts, +2.3259% ℓpw

it is a clue that the optimum wire weight has been exceeded when the current is high and ℓpw is low. Since filament wire length is only variable when wire weight and pitch are fixed, the watts and ℓpw must be off in same direction to be corrected by a change in filament length. In addition, the correction in ℓpw will be greater than the change in watts.

For example: If a lamp 54 watts and 13.5 ℓpw is desired and photometry was as follows:

A. 56 Watts and 12.6 ℓpw - were size too big or pitch is too great.
B. 52 Watts and 14.2 ℓpw - Wire size too small or pitch too tight.
C. 53 Watts and 12.8 ℓpw - Filament Wire too long.
D. 55 Watts and 14 ℓpw - Filament Wire too short.

The rewards of optimized coil designs are significant. Effective area of coil is proportional to $\sqrt{W_w \times \text{wire length}}$. Since an equal change in wire weight and wire length is generally needed, a 6% increase in wire weight for a fixed pitch results in an effective area increase of $\sqrt{1.06} \times 1.06$ or approximately a 9% increase in surface area. Since: Watts x ℓpw = Intrinsic Brightness x Effective area, a 9% increase in area results in a 9% reduction in intrinsic brightness. This can be converted to a coil temperature reduction.

T°K	Intrinsic Brightness
2700	5510
2800	7575
2900	10,220

if present temperature is 2800°K, and present intrinsic brightness is 7575 lumens/cm^2, a 9% reduction in intrinsic brightness would be 6893.25 lumens/cm^2 and a coil temperature of 2770°K.

$$2800°K - 2770°K = 30°K$$

A 1 degree drop in coil temperature relates to a 1% longer lamp life. Therefore, lamp life should be 30% longer or taken as an increase in efficiency, the ℓpw could be increased $(1.30)^{1/7}$ or approximately +3.8%.

5.0 Coil Winding and Filament Manufacture

Formula for Mechanicl Design of Filaments

List of Symbols

d = wire diameter

L = wire length

M = mandrel diameter

P_p% = primary pitch % of d

Pc = primary coil diameter

Sp% = secondary pitch % of Pc

N = number of turns

TPI - turns per inch

Pin - mandrel dia. for secondary coiling

Legs = uncoiled section of filament used for mounting

Overhang = extra wire or primary coiling extending beyond clamps

$\frac{M}{d}$ = mandrel to wire ratio primary or single coil

$\frac{Pin}{Pc}$ = Second mandrel to primary coil ratio

Sc = secondary coil outside diameter

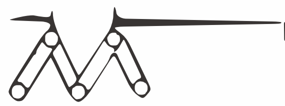
There are maximum and minimum accepted values for many of the parameters used in filament design and manufacturing

Parameter	Range for Single Coil Design	Range for Coiled Coil Design
P_p	125 - 180%	150 - 180%
Sp		130 - 180%
$\frac{M}{d}$	2.5-6	1.7 - 2.2
$\frac{Pin}{Pc}$		1.36-2.2
Pin		254 µM (10 mils) min. for C-173 Equip.
Pin Pitch %		110% Minimum

These ranges are dictated by the "coilability" characteristics of tungsten wire on the one hand, and by the sag characteristics of the finished coil in the lamp on the other, and are empirical in nature based on many years of experience with the process.

$$\text{PITCH} = \frac{1}{\text{TPI}}$$

$$\%\ \text{PITCH} = \frac{100}{\text{TPI} \times d}$$



$$\text{TPI} = \frac{N}{\text{Coil Lengh in Inches}}$$

Number of Turns (N)

$$N = \frac{\text{Coil Length}}{\text{Pitch}}$$

$$\text{Length per Turn} = \sqrt{\pi^2 (m+d)^2 + \left[\frac{P_p}{100}\right]^2} = \sqrt{\pi^2 \left[\frac{m}{c} + 1\right] + \left[\frac{P_p}{100}\right]^2}$$

or approximately $\pi\ (m + d)$ 1.5 - 2% error at typical % pitch and mandrel ratios.

$$\begin{array}{l}\text{Primary Coil Length} \\ \quad\text{or Cut Length}\end{array} = \frac{L \times P_p\%}{100 \left(\frac{M}{d} + 1\right) \pi}$$

or for more accuracy

$$\begin{array}{l}\text{Primary Coil Length} \\ \quad\text{or Cut Length}\end{array} = \frac{L \times P_p\%}{100 \left[\pi^2 \left[\frac{M}{d} + 1\right]^2 + \left[\frac{P_p}{100}\right]^2\right]^{1/2}}$$

$$\text{Primary Coil Length} = N \times \frac{P_p\%}{100} \times d$$

Primary Coil Length $= \frac{1}{TPI} \times N$

Body Length of Coil-Coil $= \dfrac{L\ P_p\% \times SP\%}{10^4 \left(\frac{m}{d} + 1\right)\left(\frac{Pin}{Pc} + 1\right)\pi^2}$

Total Filament Length (TFL)

$$TFL = \frac{(\text{Primary Coil Length} + \text{Legs} + \text{Overhang})\left(\frac{m}{d} + 1\right)\pi \times 10^2}{P_p\%}$$

Coil Outside Diameter (Pc)

$$Pc = M + 2d$$

Coil Coil Outside Diameter (Sc)

$$Sc = \left(\frac{Pin}{Pc} + 2\right)\left(\frac{m}{d} + 2\right) \times d$$

$$= Pin + 2Pc$$

Coil Coil Outside Pitch %

$$\text{CC Outside Pitch \%} = \frac{\left[\frac{Pin}{d} + 2\left(\frac{m}{d}\right) + 3\right]}{\left[\frac{Pin}{d} + \frac{m}{d} + 2\right]} \times P_p\%$$

Coil Coil Inner Pitch or Pin Pitch %

$$\text{CC Inner Pitch \%} = \frac{\left[\frac{Pin}{d} + 1\right]}{\left[\frac{Pin}{d} + \frac{m}{d} + 2\right]} \times P_p\%$$

Filament Design - Single Coil

Watts_____ Volts_____ ℓpw ______ Life _____ Mount _____ Bulb_____

Enter

____________ % Pitch (see Note 1)

____________ Watts

____________ Volts

____________ ℓpw

____________ mm Cut Length or coil body length

____________ Legs (total both ends)

____________ Stretch at mounting (1.xx)

____________Wire weight mg/200 mg

____________Wire diameter mils.

____________Total wire length (TFL) mm

____________Mandrel to wire ratio (See Note 2)

____________Mandrel diameter mils

____________Total turns per filament

____________TPI

____________Average coil diameter mils.

Note 1 -For single coils, pitch % can vary from 125% to 180%. The coil becomes stiffer and less prone to sag as pitch % decreases. Pitch % is the pitch % after mounting in lamp. For zero stretch wound pitch % and mounted pitch % are equal.

Note 2 -Mandrel to wire ratio can vary from 2-6. The lower the ratio, the longer and stiffer the coil. A ratio of 4 is average and common.

Note 3 -Gas losses result from the flow of fill gas in a convection stream past the filament. The gas carries heat away from the filament. The amount of heat lost to the gas varies with wire diameter and coil length. It is for this reason, that lamps below approximately .20 amps are usually vacuum lamps. Above one amp, gas loss is not a serious factor. Gas loss is reduced as current and wire size increases and lamps with coil-coil filaments have gas losses roughly 1/3 of single coils of the same current.

Filament Design - Coil-Coil

______Watts ______Volts ______ pw ______ Life ______ Mount ______ Bulb

Enter

________ % Primary pitch (see Note 1)

________ % Secondary pitch (see Note 2)

________ Watts

________ Volts

________ ℓpw

________ mm Body length secondary

________ mm Total both legs

________ Mils primary mandrel

________ mm Overhang total both ends (see Note 3)

________ Wire weight (mg.)	________ Total turns primary
________ Wire diameter (mils)	________ TPI primary
________ TFL (mm)	________ Pin to coil ratio (see Note 5)
________ Mandrel to wire ratio (See Note 4)	________ Pin dia. (mills.) (See Note 7)
________ Mandrel dia. (mils.)	________ Pin pitch % (See Note 6)
________ Avg. coil dia.(mils.)	________ Turns secondary
________ Length of primary (mm)	________ Coil-Coil O.D.

Note 1 - Primary pitch can vary from 150 to 190%. Since lamp quality improves with decreasing pitch, 150%-170% primary pitch (P_p) is suggested.

Note 2 - Secondary pitch (Sp) can vary from 125% to 180%. Less than 180% is recommended. The value to be entered is % pitch after mounting, not as wound. Sylvania CC-8 lamps have an 8% stretch and European CC-9 types have zero stretch. For example, a CC-8 coil wound at 167% Sp and stretched 8% at mounting would have a final Sp of 180%.

Note 3 - Sylvania lamps are mounted with some of the coil extending beyond the clamps. The value to be entered for overhang is the total overhang desired in mm. European lamps are designed for no overhang. Therefore, the value entered is zero for CC-9 coils for mounting with no overhang.

Note 4 - The mandrel to wire ratio $\frac{m}{w}$ can vary from 1.5-3. The coil becomes stiffer and less prone to sag as $\frac{m}{w}$ decreases. $\frac{m}{w}$ is restricted by coil body length and acceptable pin to primary coil ratio (see Note 5).

Note 5 - The secondary mandrel or pin to primary coil ratio can vary from 1.4 to 2.2. The lower the ratio the longer and stiffer the coil.

Note 6 - Pin pitch % is the % pitch of the primary coil where it is bent around the secondary mandrel. The minimum value is 105%.

Note 7 - For C-173 coil winder, minimum pin size is 10 mils.

Note 8 - Changes in P_p and S_p affect wire weight and TFL.

Note 9 - Changes in $\frac{m}{w}$, body length and pin to primary coil ratio are limited by current but can be played against each other for best coil geometry.

Note 10- Gas losses result from the flow of fill gas in a convection stream past the filament. The gas carries heat away from the filament. The amount of heat lost to the gas varies with wire diameter and coil length. It is for this reason, that lamps below approximately .20 amps are usually vacuum lamps. Above one amp, gas loss is not a serious factor. Gas loss is reduced as current and wire size increases and lamps with coil-coil filaments have gas losses roughly 1/3 of single coils of the same current.

Note 11- Coil design depends on mounted filament pitch. Springback at coil winding must be known and allowed for in design data. Low $\frac{m}{d}$ values and high $\frac{Pin}{Pc}$ values increase springback %.

5.1 Filament Wire

Pure tungsten is doped with various materials to make lamp wire. There are essentially two categories of lamp wire--sag and non-sag (NS) lamp wire.

Types of Tungsten Wire

Sylvania manufactures wire having the following descriptions:

NS is the Sylvania designation for non-sag tungsten wire for filaments and supports in fluorescent and incandescent lamps, electronic-tube grids and heaters, and electric furnace elements. It is available in the broadest range of standard processes, and has the widest variety of applications.

VM is the Sylvania designation for tungsten wire furnished in either stranded or single-strand form that has been processed specifically for vacuum-metallizing applications. (Refer to technical information bulletin "Tungsten Strand for Vacuum Metallizing.")

TH is the Sylvania designation for tungsten wire containing 0.75% to 1.1% thoria. Its principal use is for power-tube filaments and for vibration service in some types of incandescent lamps.

RW is the Sylvania designation for tungsten-rhenium wire. (Refer to technical bulletin on Sylvania Tungsten-3% Rhenium Wire.)

AK is the Sylvania designation for low Ni, Fe, and Cr. non-sag wire for filaments in GLS and halogen lamps of some types.

<u>Standard Processes Non-Sag Tungsten Wire</u>

NS-10 Designates as drawn wire, which retains the black finish from the graphite drawing lubricant. The wire is unstraightened and has high tensile strength. NS-10 is generally used for coils for incandescent and fluorescent lamps.

NS-20 Designates NS-10 wire which has been straightened but not cleaned.

NS-30 Designates NS-10 wire which has been chemically cleaned but not straightened.

NS-50 Designates tungsten wire which has been cleaned, straightened and annealed in a reducing atmosphere. It is generally used in electronic-tube grid and heater applications where optimum straightness and low tensile strength are required.

NS-55 Designates tungsten wire which has been chemcially cleaned, straightened and stress-relieved in a reducing atmosphere. NS-55 wire has good straightness and intermediate tensile properties, finding broad usage wherever a cleaned and straightened tungsten wire is required. Generally it is used for electronic-tube grids and heaters and for lamp coils, but it serves other applications when a cleaned and straightened tungsten wire is needed.

NS-60 Designates tungsten wire which has been partially straightened under heat and tension, and chemically cleaned. NS-60 retains the high tensile strength of the as-drawn wire.

NS-80 Designates an unstraightened, electropolished wire with a high tensile strength. It is generally used in sizes below diamond-die drawing range and may be used in larger sizes where the very smooth electropolished surface is desired.

NS-85 Designates an electropolished wire with a low tensile strength, which has been straightened with heat in a reducing atmosphere. Straightness and tensile strength are comparable to those of NS-50

NS-86 Designates an electropolished wire having intermediate tensile strength and straightness. Tensile strength and straightness are comparable to those of NS-55.

NS wire is used for all A-line GLS lamps.

TH wire is used in miniature automative vibration service lamps.

RW wire is used in applicance lamps, telephone lamps, long-life-sub-miniature lamps, etc. RW filament lamps are usually vacuum lamps.

AK wire is used for some Halogen lamp types.

NS-87 Designates a partially straightened electropolished wire with high tensile strength. Straightness and tensile strength are comparable to those of NS-60. NS-87 wire is recommended for electron-tube grids at sizes 0.5 mil and below, where a high tensile strength and a very smooth finish are required for efficient operation of automatic grid-winding machines.

THORIATED TUNGSTEN WIRE

TH-10 Designates black, as-drawn wire containing thoria.

TH-20 Designates TH-10 wire which has been straightened but not cleaned.

TH-30 Designates TH-10 wire which had been cleaned but not straightened.

TH-55 Designates TH-10 wire which has been chemically cleaned and straightened.

TH-60 Designates TH-10 wire which has been partially straightened under heat and tension, and chemically cleaned. TH-60 retains the high strength of as-drawn wire.

Non Sag Wires

Process	Surface Finish	Tensile Strength	Straightness	Available Size Range
NS-10	Black	High	1	0.17 mg/200mm to 100 mils (2540μ M)
NS-20	Black	High	2	0.45 mg/200mm to 100 mils (2540μ M)
NS-30	Clean	High	1	0.45 mg/200mm to 100 mils (2540μ M)
NS-50	Clean	Low	4	0.45 to 50 mg/200mm
NS-55	Clean	*Intermediate	3	0.45 mg/200mm to 85 mils (2519μ M)
NS-60	Clean	High	2	0.45 to 12 mg/200mm
NS-80	Polished	High	1	0.04 mg/200mm to 10 mils (254μ M)
NS-85	Polished	Low	4	0.45 to 50 mg/200mm
NS-86	Polished	Intermediate	3	0.45 mg/200mm to 10 mils (254μ M)
NS-87	Polished	High	2	0.17 to 68 mg/200mm

THORIATED WIRES

Process	Surface Finish	Tensile Strength	Straightness	Available in Size Range
TH-10	Black	High	1	1.25 mg/200mm to 40 mils (1016 μ M)
TH-20	Black	High	2	1.25 mg/200mm to 40 mils (1016 μ M)
TH-30	Clean	High	1	1.25 mg/200mm to 40 mils (1016 μ M)
TH-55	Clean	Intermediate	3	1.25 mg/200mm to 40 mils (1016 μ M)
TH-60	Clean	High	2	1.25 mg/200mm to 40 mils (1016 μ M)

Straightness: 1 = unstraightened
2 = partially straightened
3 = intermediate straightness
4 = best straightness

MEASUREMENT OF WIRE SIZE AND TOLERANCE

Wire sizes 20 mils (508μ M) and larger are expressed in mils (thousandths of inches) or mm. Wire sizes below 20 mils are expressed in milligrams per 200 millimeters (mg/200mm).

The relationship of milligram weight to diameter in mils can be shown as:

For NS wire: $\text{mg/200 mm} = 1.943 \times (\text{ diameter in mils })^2$

$$= 1.943 \times \left(\frac{\text{diameter in micron meters}}{25.4}\right)^2$$

For 1% TH wires: $\text{mg/200 mm} = 1.905 \times (\text{ diameter in mils })^2$

$$= 1.905 \times \left(\frac{\text{diameter in micron meters}}{25.4}\right)^2$$

Calculated milligram weights are rounded off by Sylvania to a value consistent with the sensitivity of weighing (usually to the nearest 0.01 mg).

Wire tolerances are based on the center size and are expressed as the center size plus or minus milligram/200mm, percent of milligram weight, or percent of diameter as outlined in the following table:

Wire Size Range	Tolerance Expressed as	Standard Tolerance	Other Available Tolerances
0.08 mg/200mm to 0.67 mg/200mm	mg/200mm	Varies with center size	±0.03, ±0.025 ±0.02, ±0.015, ±0.01 ±0.005 mg/200mm
0.68 mg/200mm to 19.9 mils (505μ M)	percent of milligram weight	±3%	± 2 1/2%, ±2%, ± 1 1/2%, ±1% ± 1/2%
20 mils (508 μM) and larger	percent of diameter	±1 1/2%	± 1 1/4%, ±1%, ±3/4%

Different lamp wire manufacturers have other symbols for wire types:

GTE Sylvania	General Electric
NS	218
NS-55	218 CS
TH	NF
TH-10	NFB

In the as drawn condition, tungsten is fibrous and very strong and ductile. When heated to lamp operating temperature, the wire recrystallizes. The dopants in NS wire cause the crystals to grow faster along the wire than across the diameter. The result is inter-locking crystals that prevent crystal slippage (sag or offset). The dopants in TH wire delay or prevent large crystals from growing, the result is a sag but non-birtle wire for lamps subject to shock and vibration. RW wire dopants also delay recrystallization and result in a sag wire for use in special lamps.

The quality of the lamp wire is critical. The specification normally will indicate the material to be used by manufacturer's code or codes, e.g., NS-10. The material may be cleaned, etched, polished or as-drawn material. Special tensile and elongation characteristics may be required. The wire has important size and weight tolerances. The wire's camber or curliness may vary. Each of the variations in the starting material requires significant process adjustment. Very few filaments are made using straight wire materials. Some large electronic devices use folded wire heaters.

Today, incandescent lamp filaments are single or double helix type filaments, normally called single-coil and coiled-coil filaments. The coiling is done on a mandrel which is later removed.

Contaminants are a major problem.

Tungsten contamination results in:

1. Brittleness, due to the reduced ductility of the contaminated surface and consequent cracking of the tungsten due to its notch sensitivity.
2. Bulb Wall Darkening due to the higher evaporation rates of the contaminants.
3. Objectionable Sag due to an interstitial such as carbon, and the resultant tungsten carbide dispersed in the grain boundaries and within the grains.

Nickel, iron and moly are the most common contaminants in filament and cathode manufacture. All three of these elements are substitutional in nature; that is, they are diffused into the tungsten lattice by substitution. The iron and nickel are incompatible with the tungsten, and form brittle

second phases and intermetallics, which show up as small, equiax grains, the depth of which depend on the temperature and concentration of the contaminants. Moly is compatible with tungsten, does not form second phases, does not change the structure of the tungsten wire, and is usually manifest as bulb wall darkening when the filament is burned.

Iron Contamination

Typical problems of iron contamination are brittle coils at inspection after mandrel dissolving. This type of contamination is usually accomplished by either too high a temperature at annealing the coil on steel mandrel, or by sintering with incomplete mandrel dissolving. Another usual problem of iron contamination is "splintering" of the tungsten wire where it was in contact with an iron mandrel during annealing.

Iron contamination of filaments intended for tungsten halogen lamp use is much more serious because iron ties up the halogen content in relatively non-volatile compounds, resulting in early lamp blackening due to insufficient halogen.

Molybdenum Contamination

Molybdenum contamination of a tungsten filament can occur readily under certain conditions. Molybdenum is usually present in tungsten wire as a few parts per million. Usually if this value is below 50.0 ppm no difficulty will be encountered. Many filaments are wound on molybdenum manderels and then strain relieved by heating at a temperature of about 1550°C for as much as ten minutes. Filament wire having a high ratio of surface area to mass will pick up considerable molybdenum at this temperature through a diffusion process. For this reason molybdenum supports are not used in high temperature filament designs, being replaced by ones of tungsten. In general, filament wire below 5.0 mgs/200mm is not subjected to such high temperature treatments. More often steel mandrels are used for these sizes and the temperature for strain relieving maintained below 1100°C.

Barrier coatings have been developed to reduce contamination of the filament by the mandrel. It may be noted that contamination is much more likely to take place where many crystals boundaries exist as in the drawn condition.

When the moly mandrel is not properly cleaned the central core of the mandrel will dissolve from the cut ends of the coil leaving the dirty surface of the original moly mandrel intact. This condition is known as mandrel shell. Only the surface of the mandrel - the mandrel shell - remains. (This mandrel shell is so thin that it is translucent. This condition can usually be traced to a leaking cooling chamber in a sintering furnace.)

Carbon Contamination

Most everything that tungsten comes in contact with may contain or have a coating containing carbon on it. Once these carbon containing materials, e.g., graphite, oils, greases, fibers, etc., react with the heated tungsten or molybdenum, complicated chemical changes take place. Carbides are first formed embrittling the filament and filament supports of the lamp.

(1) $W + C = WC$ M.P.3140°C ± 50°C

(2) $2W + C = W_2C$ M.P.3130°C ± 50°C

(3) $2Mo + C = Mo_2C$ M.P.2690°C ± 20°C

(4) $Mo + C = MoC$ M.P.2700°C

When areas of a tungsten filament become carburized, the melting point is reduced by about 300°C, leading to early failures at the affected points. The higher vapor pressures of the carbides contribute to early blackening of the bulbs. The microstructure of tungsten is radically affected by carbon which thus detrimentally changes the sag characteristics of the filament.

Tungsten carbide can be decarburized by heating in a wet hydrogen atmosphere for extended periods. Time depends upon amount of carburization.

5.2 FILAMENT MANUFACTURING

Filament coiling is done by winding the filament wire on a mandrel, which is subsequently removed either by dissolving, as for continuous winding process and coiled coil, or by mechanical extraction, as for the automatic coiling process. Therefore, two main constituents for coiling of filaments are the filament wire and the mandrels used.

To manufacture a single coil incandescent lamp filament, specific data is required. (See Section 5.0 for additional data.)

Mount Type Filament Designation

Filament Wire Type

Filament Wire Size and Tolerance

Non-sag (NS) Wire $\quad mg/200 = 1.943 \left(\frac{\text{wire diemeter in}\,\mu\,\text{M}}{25.4}\right)^2$

Thoriated (TH) Wire $\quad mg/200 = 1.905 \left(\frac{\text{wire diameter in}\,\mu\,\text{M}}{25.4}\right)^2$

Mandrel Wire Type

Mandrel Wire Size and Tolerance

Moly Wire $\quad mg/200 = 1.029\ (\text{wire diameter in mils})^2$

Steel Wire $\quad mg/200 = 0.792\ (\text{wire diameter in mils})^2$

Turns per inch (after coiling is completed) or turns per mm

Total turns per filament

Leg length if any

If coiled coil, additional data is required

Pin or second mandrel size in mils or microns

Secondar coiling TPI or TP mm

Secondary coilina turns per section (TPS)

Leg Length each end

NOTE: In the United States, diameters are in mils and length in millimeters.

In Europe, diameters are in μ M or millimeters and length in millimeters.

5.2.1 Coil Winding Equipment

Different types of filaments require different types of coil winding equipment. In general, there are three types of coils:

A. Leg type single coils or leg type coiled coils.

B. Continuous coils to be used as single coils or to be used as primary winding for a coiled coil filament.

C. Special coils both single coil and coiled coil even triple coil. These coils require special equipment and hand working.

Basically, there are five types of coil winding equipment for high production A-line lamps.

I. <u>S81 Coil Winder</u>

The S81 Coil Winder makes continuous coiling. The filament wire is wrapped around the mandrel. The turns per inch (TPI) are controlled by the rotational speed of the head and the linear speed of the mandrel. The S81 is used to make either single coils or primary coiling for coiled coil filaments.

II. <u>Syl-Coil Coil Winder</u>

The Syl-Coil Coil Winder is used for the same purpose as the S81 Machines. It runs faster and puts less stress on the filament wire.

III. <u>4G Coil Winder</u>

The 4G Machine is similar to the S81 except that the mandrel travel speed can be altered such that a skip space coil is wound. The result is a leg type coil but the leg is not straight. The leg is really one or more open pitch turns. A special machine called the Electronic 4G has the ability to stop the winding head and advance the mandrel and then start up again. This unit can make leg type coils with nearly straight legs. To obtain the individual leg coils, the coiling is cut in the middle of the skip space.

IV. Winders with Retractable Mandrel

A. <u>C173 Coil Winder</u>

The C173 Coil Winder makes leg type single coils or leg type coiled coils. The C173 is unique in that it has a retractable mandrel. In operation, the wire or coiling is held by the head clamp and wound around a steel mandrel. When the desired number of turns are completed, the head rotation stops and wire guide continues back to make rear leg of coil. A cutter then comes in and cuts filament wire and end of rear leg. The mandrel is then retracted and the completed coil is dropped into a tray.

The C173 Coil Winder has some limitations:

Mandrel or Pin	254μ M (10 mils) min, diameter
Number of Turns	100 turns maximum

B. A similar coil winder called HS152 is used to make leg type coils for miniature lamps. The major difference is that before the mandrel is retracted, a coil transfer device holds the coil and instead of dropping the finished coil, the coil is transferred directly to the lead wire clamps. Wire used on the HS152 equipment is always clean because the coil goes directly into a lamp with no further treatment.

C. There is also a G173 Machine. The G173 unit has the ability to heat wire being wound on mandrel and to form legs to special shapes. There is less twist put in filament wire on a G173 than on a C173 or HS152 because the wire is fed perpendicular to mandrel instead of parallel to mandrel. The G173 also has an adjustable head stop so that the coil legs can be lined up with each other.

V. <u>S & H Coil Winder</u>

The S & H Coil winder is used for special shapes for projection lamps, etc. The S & H Machine normally makes a leg type coil where the legs are perpendicular to coil body"U" shaped coil. The S & H Machines can be fitted with a variety of special tools for unique filament shapes.

Black wire is usually used for S81, Syl-Coil, and 4G Machines. C173 can use either black or clean, but black is preferred. The HS152 always used clean and straightened wire.

The following controls should be exercised in the selection and use of filament wire:

1. The size of the filament wire must be accurately determined. Wrong size wire will give coil of incorrect wattage and efficiency ratings.
2. The wire should have a smooth, round contour. Wire with poor contour is difficult to coil at uniform pitch.
3. Wire with abnormal point-to-point variations in resistance may affect rating and should not be used.
4. Split wire, or wire which tends to split or sliver during coiling, may cause low efficiency and short life. Wire lots showing these tendencies should be rejected.

5. Brittle wire is very undesirable. It will break frequently during coiling and is likely to produce fragile coils.
6. Wire should not be too soft. Soft wire will appear to function well on the coiling machines but tends to stretch during coiling causing low and non-uniform ratings and may also sag in high temperature lamps.
7. The tensile strength of the filament wire should be uniform and should be chosen with due consideration being given to such factors as pitch and mandrel ratios, recoil, and actual limitations of the particular coiling machine.

5.2.2 Wire Tensile Strength vs Coiling Tension

The tensile strength of filament wire is, to a certain extent, a measure of its working qualities and is therefore very important. Usually, wire with low tensile strength has a low elastic limit but will withstand considerable additional tension and stretch before breaking. On the other hand, wire with high tensile strength has a high elastic limit but will not stand much additional tension or stretch before breaking.

Experience indicates that best coiling results will usually be obtained if the tension on the wire at the mandrel during coiling is just above its elastic limit. If the tension is below this point, there is too much tendency for the turns to unwind when the wire is cut after coiling. This affects lamp rating and changes the physical dimensions as well as the leg positioning of the finished coils. If the tension is too high, there is too much stretch and possible breakage of the wire during coiling. Abnormal stretch reduces the diameter of the wire and seriously affects lamp rating.

In some cases, the desired working characteristics may be attained by applying heat to the wire during coiling.

Ordinarily, the larger the wire diameter, the lower should be the inherent tensile strength per unit cross-sectional area of the wire. This is because, as wire diameters increse, it becomes difficult to apply sufficient tension during coiling to exceed the

elastic limit of the wire and thus prevent an excessive amount of recoil. Conversely, as wire diameters decrease, it becomes difficult to apply low enough tensions to prevent an excessive amount of stretch.

The particular mandrel and pitch ratios of certain coils are primarily responsible for the need to specify tensile strength. These ratios are found to be necessary in order to obtain the concentrated light source dimensions, coiling and mounting machine limitations.

Type of Tungsten Wire

The types of tungsten wire available are described in Section 5.2.

The Effect of Carbon on the Microstructure of Tungsten

The presence of carbon has harmful effects on the structure of tungsten, and therefore great care should be exercised to insure that tungsten filaments are as free from carbon as possible. Tungsten filaments contaminated with carbon, distort and sag when they are operated at high temperatures and are extremely brittle at room temperature. In the process of manufacturing of coils and finished lamps, there are occasions where carbon may contaminate the tungsten: In the drawing of the wire, aquadag (a form of carbon) is used as a lubricant; In the manufacture of coils, oil and grease, either intentionally or inadvertently, may get on the tungsten; In the manufacture of lamps, carbon in the form of oil vapor may be introduced.

Carbon is only one of those undesired impurities that have harmful effects on the structure of tungsten. Other impurities include oxygen, nickel, iron and molybdenum which have effects similar to those of the interstitial atoms of carbon. Small concentrations will increase the transition temperature of tungsten filaments.

One characteristic of tungsten is the narrow temperature range over which its properties change from ductile to brittle characteristics. This narrow temperature range is the so-called low

temperature brittleness point or transition temperature brittleness point or transition temperature region. The transition temperature gives an index of the ductility of tungsten filaments, a low transition temperature being desirable.

5.2.3 MANDRELS

Mandrel materials, useful in filament coiling or forming, are iron, steel and molybdenum. They may be used as cleaned, as drawn, coated, e.g., copper on steel. Generally, the form is round, as in wire; however, rectangular shapes are used for special filament shapes such as the C-bar 6 type. The exact control of size is important to match the size of filament wire specified. The mandrel material must also have controlled elongation and expansion characteristics; otherwise, the filament specification cannot be met. Although most mandrels are removed from the primary coiling chemically, secondary coiling is sometimes done on a retractable mandrel.

Choice of mandrel material depends on mandrel size and heat treatment of the coils on mandrel.

When very fine mandrel wire is required, (less than 60µ M). steel becomes too weak and molybdenum wire must be used. When coils on mandrel are to be treated at temperatures over 1200°C, it is essential to use Mo-mandrel as at these high temperatures diffusion of iron into tungsten causes brittle coils. At lower temperatures steel can be used.

Treatment of coils on mandrel at temperatures over 1200°C is necessary when manufacturing coiled coils and in cases where length differences in single coils must be smaller than $\pm$ 0.5 mm.

Selection and Care of Mandrels

The following controls should be used in the selection and care of mandrels for C173 and HS152 Coil Winders.

1. The diameter of the mandrel affects filament length and consequently must be accurately determined.
2. The mandrel should be round, since out-of-roundness affects filament length and promotes coil distortion.

3. The surface of the mandrel should be free of any imperfections which might score or otherwise damage the coil. Rusting (of steel wire) should be guarded against by proper storage before use. Mandrels used for automatic coiling processes require a bright smooth finish so the coils will not bind on stripping. Such mandrels may be polished by wiping lightly with crocus cloth, but care must be taken not to change the diameter.
4. The mandrel should be of correct hardness to render it best suitable for its particular application. Mandrels used for automatic coiling processes should be hard enough to prevent grooving or excessive wear, but not so brittle as to cause frequent breakage on the machine.

5.2.4 EFFECT OF FILAMENT WIRE SIZE AND MANDREL SIZE TOLERANCES

Lamp filament wire is usually purchased to a tolerance of $\pm$ 3% of wire wgt/200 mm.

If not compensated for:

+ 1% wire wgt. = +0.846% watts, + 0.578% ℓpw.

The change in lamp rating can nearly be compensated for by a change in filament wire length:

+ 1% Filament Length = -0.672% Watts, -2.33% ℓpw.

This is accomplisyed by a change in mandrel size.

$$\text{Filament Length} = \text{Coil Length} \left(\frac{M}{d} + 1\right) \times \frac{10^2}{P_p\%}$$

When coil length and P_p are held constant, filament length will vary with a change in either M or d.

Since M and d are in mils or microns and wire tolerances are usually expressed in mg/200, the following relationships are needed:

Wire diameter in Mils = A (Wire weight. in mg/200)$^{1/2}$

Wire diamater in Microns = 25.4 A (wire wgt. in mg/200)$^{1/2}$

A = .717 for NS Wire

A = .724 for TH Wire

A = 0.987 for Moly Wire

A = 1.124 for Steel Wire

Or a 3% change in moly mandrel weight equals approximately 1.5% change in filament length:

$$M_1 = 0.987\ (\text{wire wgt.})^{1/2}$$

$$M_2 = 0.987\ (1.03)^{1/2}\ (\text{wire wgt})^{1/2}$$

$$M_2 = 1.014889\ M_1$$

Or filament length is increased by approximately 1.5%.

The following table shows the compensation:

+ 3% wire wgt. = + 2.5% Watts, + 1.8% ℓpw

+ 3% Mandrel wgt.= +1.5% Filament Length

+ 1.5% Filament Length = -1.0 Watts, -3.5% ℓpw.

Net Effect = + 1.5% Watts, -1.7% ℓpw.

It can be seen that by matching wire and mandrel, the lamp readings can be controlled to a large extent.

This data is empirical because the P_p% is held constant.

5.2.5 EFFECT OF COIL WINDING PARAMETER TOLERANCES

Wire can vary from specification within a spool. Wire can stretch during coiling which reduces wire diameter and wire weight. Wire can recoil after cutting resulting in a longer filament length. Recoil also can change TPI.

The resulting quantitative effects of TPI changes are difficult to generalize because the reference or base line percent pitch varies with the lamp type. For a coil having an open pitch of 185-190% changes of 5% in TPI would not materially change the ratings. On the other hand, a coil having a close pitch of 140%, would be quite sensitive to TPI variations, as small changes in this range produce large changes in the mutual heating effects between the turns. This increase in mutual heating effect would increase the light output and efficiency but would decrease the wattage and life.

5.3 Annealing of Coiled Filaments

Most designs require that the filament wire be severely deformed. For instance, the wire may be coiled around a mandrel which is sometimes less than twice its diameter. In other cases the deformation is less; however, as the coiling takes place the filament wire is under a constant tension of known magnitude. Depending on such characteristics as tensile strength, temperature at coiling, speed of coiling and winding tension, filaments are made to exacting dimensions despite the deformation. During the filament forming or winding, severe mechanical stresses are introduced and these must be relieved in order that the geometry of the filament can be preserved. In order to do this strain relieving, a process known as "annealing" is required. It essentially consists of pulling the mandrel, with its filament coil in through a tube furnace whose temperature, atmosphere and process rate are closely controlled. Generally, the atmosphere is reducing rather than neutral or oxidizing. When other than clean wire and mandrel is present, water or carbon dioxide in discrete quantities is needed and is added to the gas, thereby reacting chemically to clean up carbon as the following equations denote:

$$2C + H_2O \longrightarrow 2CO + H_2$$

$$C + CO_2 \longrightarrow 2CO$$

The temperature used may vary from 1000°C to 1600°C depending on the materials involved. Processing rates also vary substantially for the same reasons.

<u>Steel Mandrel</u>

<u>Cleaned Tungsten Wire</u>

in wet hydrogen

at 1100 - 1200°C

<u>Mo-Mandrel</u>

<u>Cleaned Tungsten Wire</u>	<u>Black Tungsten Wire</u>
in wet hydrogen	in wet hydrogen
at 1350 - 1600°C	at 1200 - 1400°C

In the case of a coiled coil filament design, the "annealing" of the primary coiling is a requirement before the secondary coiling operation is started.

Again the stresses that are introduced in secondary coiling must be relieved. Singly coiled filaments are cut to required length while on

the mandrel by a special cutting machine, which produces coiling of exact cut lengths. The cut pieces of coiling may be further treated in a sintering furnace for several minutes at high temperatures prior to the mandrel removal, or the mandrel may be first removed. This furnace treatment is known as "sintering." It insures more complete stress relief and should insure removal of extraneous contamination. The process is a batch type heat treatment performed in a controlled reducing atmosphere furnace at temperatures in the range of 1100 - 1657°C.

Sintering is done at various temperatures depending on coil types. The code for sintering is a letter and number combination where the letter designates a temperature and the number the time at temperature.

B-2	1180°C	for	2 minutes
B-10	1180°C	for	10 minutes
C-10	1525°C	for	10 minutes
G-10	1675°C	for	10 minutes

Sintering is usually done in dry hydrogen.

5.4 Removal of Mandrels

Mandrels are removed chemically by dissolving in acid.

Steel

In boiling HCl (sp. g. 1.15)

Rinse with plenty of hot distilled water and dry after dipping in alcohol.

Molybdenum

In a mixture of
4 parts HNO_3 (sp. g. 1.25)
4 parts H_2SO_4 (sp. g. 1.85)
2 parts water

Rinse with plenty of hot distilled water and dry after dipping in alcohol.

In both cases, coils must not be kept in the dissolving agents for no longer time than is necessary for removal of the mandrel.

When dissolving Mo-mandrel, care should be taken that the reaction does not get out of hand. Rather small quantities of coils only should treated at one time.

Whenever acids are used, selected materials are required for baskets, sinks, piping, etc. These materials must not be affected by the acids

which might cause contamination, or removal of filament material. Rigid controls must be exercised in this process. Reaction products from the operation are generally toxic and obnoxious. Specially designed equipment is necessary to neutralize the spent acids and fumes.

5.5 Stabilized Filaments

Stabilized filaments are used in precise light sources for optical instruments such as projection devices and as indirect cathode heaters for power transmitting electron tubes.

The filament is placed on a tungsten form which holds it exactly as required. It is then heated at a carefully controlled rate and temperature in order to produce a fully recrystallized structure. The filament is now brittle, so careful handling and mounting are required. No stretching or distorting can be allowed. Treatment schedules very by type. When specifications are followed little or no distortion will take place during the life of the filament and this is of utmost importance to precision optical systems and indirectly heated cathods used in transmitter tubes. The stabilizing process can be conducted either in a high vacuum in the presence of non-reactive gas or in a reducing atmosphere. The final performance of the filament dictates the process details.

Stabilizing temperatures and times are in the order of 2450°C for one minute.

Coils stabilized in vacuum are cooled in nitrogen.

No materials other than tungsten are allowed in the stabilizing furnace.

5.6 Inspection of Coiled Filaments

Inspection begins with checking the lot for all geometric dimensions and filament weight. Non-uniform and otherwise defective filaments are removed. Tests for fragility are performed such as stretching the coil to a predetermined length and recording breakage. Sometimes coils are bounced in an air column. Non-uniform pitch is observed by using microscopic instruments. Statistical quality control methods are used for the greater portion of the production. Some critical types require 100% inspection.

After the inspection has been completed the filaments are placed in special containers with complete identification and then removed to the shipping area where they are forwarded to the customer.

5.7 Coil Schedule Card

All coils made by Sylvania and delivered to a lamp plant have schedule card attached. One spool of lamp wire comprises one schedule. The schedule card lists all pertinent information relating to the manufactures of that particular lot of filaments.

Figure 2.141 is a blank coil schedule card.

COIL SCHEDULE CARD

DES. LPW	SYLVANIA ELECTRIC PRODUCTS, INC. ENGINEERING								ISSUE DATE
CODE	TYPE								
SCHEDULE NUMBER	DATA LTR	FINISHED LGT.	FIRST QUANTITY	REV. QUANTITY					
GETTER NUMBER	DATE	%	FIRST WEIGHT	SECOND WEIGHT	OP. INT.	DATE			
WIRE WGT.	WIRE TYPE	WIRE LOT	DATE DRAWN	METERS ISSUED	METERS USED				
MAND.	TYPE	SIZE	WEIGHT RANGE	WGT. USED	SUPPLIER	LOT	D. D.		
# 1			/						
# 2			/						
# 3			/						
T F L	COIL WGT.	TOTAL WGT.	FIN. T P I CK.	PLANT	STABILIZED	DATE			
S81 4G	# 1 MACH.	# 1 T P I	T P I CK.	OP. INT.	DATE	# 2 MACH.	# 2 T P I	T P I CK.	OP. INT. DATE
NO. SEG.	IND. T P F	ACT. T P F	T P F CK.	LGT. ENDS	BODY	SPACE	4G WGT.		
ANN.	FURN.	TEMPERATURE	SPEED	TENSION	OP. INT.	DATE	200 M M		
# 1							THEO.	ACT.	
# 2							%	OP. INT.	
C173 S. H.	# MACH.	T P S	PIN	CONTROL LIMITS /	WGT. RUN	OP. INT.	DATE		
CUT	# MACH.	CUT LGT.	CUT LGT.	OP. INT.	DATE	SINTER 1 CODE	FURN.	OP. INT.	DATE
TREAT	1 OP. INT.	DATE	2 OP. INT.	DATE	2 CODE	FURN.	OP. INT.	DATE	
FINISH	FOLD	OP. INT.	INSERT	OP. INT.	MINOR NO.	OP. INT.	END STR.	OP. INT.	
QUALITY	OPAL INT.	DATE	BAL. INT.	DATE	PULL TEST	OP.	BOTTLE TEST	OP.	
NOTES:									

The coil schedule card is general. Only the necessary data for a particular coil is filled in by the coil manufacturing plant. Most of the terms on the card are abbreviated. The following list explains the schedule card items.

SCHEDULE CARD TERMS

Code	Product numbers for ease and computer
Type	Description - watts, volts, life, etc.
Schedule Number	For customer reference
Data	Reference to specification data letter
Finished Length	Actual finished length of lot
First Quantity	Actual amount of coils
Revised Quantity	Actual amount of coils if first quantity is revised.
Getter Number	Not applicable at coil plant
First Weight	Generally not used
Second Weight	Generally not used
Wire Weight	Weight of wire used
Type	Wire type - black, clean, etc.
Wire Lot	Wire Lot, Ingot, etc.
D. Date	Wire draw date
Mand	Mandrel
Type	Mandrel type - moly, steel, etc.
Weight Range	Weight limits of mandrel
Wgt. Used	Actual weight of mandrel used
Supplier	Mandrel supplier - Sylvania, etc.
Lot	Mandrel lot identification
#1, #2, #3	Tungsten and mandrel are matched
TFL	Total tungsten per filament
Factor	For internal coil use
Coil Weight	Weight of individual coil
Total Weight	Total weight of all filaments
Fin. TPI	Finished turns per inch - not used in GLS
Fin. TPS	Finished turns - not used in GLS
Pull Test	Check for brittle coils
Bottle Test	Check for brittle coils - not used in GLS
No. 1 Mach.	First winding machine
No. 1 TPI	Turns per inch - first winding
No. 2 Mach.	Second winding machine - coiled coils
No. 2 TPI	Turns per inch - second winding
Ind. TPS	Turns - machine setup-gap coiler
Act. TPS	Turns - actual-gap coiler
200 MM Theo Actual, %, TPI, CK.	Used for internal control of coil weight
No. Seg.	Number of coil segments
Body	Length of coiled section
Lgt. Ends	Length of coil ends
Space	Length of gap
4G FCW Limits	Coil weight limits for gap coiler

#1 & 2 Furn.*	Furnace number at annealing
#1 & 2 Temp.*	Annealing temperature
#1 & 2 Speed*	Annealing speed
C13 No. Mach.	Number of cutting machine used
C13 Cut Lgt.	Actual cut length of coil
C173 or SH	Coiling machines used
No. Mach.	Number of machines used
TPS	Turns in coil
Pin	Second coiling mandrel used
Control Limits	Weight limits - second coiling
WGT. Run	Actual weight of second coiling
Sintering	Heat treating furnace
#1 & 2 Code*	Heat treating code - temp., time
#1 & 2 Furn.	Number of furnace used
Process Notes	For use internally at coil plant
Notes	Additional pertinent information

*#1 & 2 - In some cases the operation may be done twice

6.0 INCANDESCENT LAMP LIFE

The life of an incandescent lamp is controlled by four major variables.

1. The temperature of the filament
2. The mass of the filament
3. The burning environment of the filament
4. Manufacturing defects such as cracks or nicks in the filament wire, close turns in coiled filaments, loose clamps, etc.

The higher the filament temperature, the higher the luminous efficiency and the higher the tungsten evaporation rate. The following table shows the evaporation rate in vacuum and luminous radiation as a function of filament temperature.

The measurements of ℓpw at various temperatures in vacuum were determined by Jones and Langmuir, Forsythe and Worthing, Forsythe and Watson, and Smithells. The Forsythe data published in the Smithsonian Plysical Tables (1954) is considered to be most accurate.

Temperature °K	ℓpw (Forsythe)	Evaporation Rate (Szwarc)
2400°K	9.21	1.74×10^{-10}
2500	11.46	1.00×10^{-9}
2600	14.01	5.07×10^{-9}
2700	16.93	2.27×10^{-8}
2800	20.03	9.11×10^{-8}
2900	23.20	3.32×10^{-7}
3000	26.60	1.11×10^{-6}
3200	34.5	9.96×10^{-6}
3400	43.5	6.88×10^{-5}
3655	53.1	5.95×10^{-4}

Examination of the data by the computer shows that from 2400°K (9.21 ℓpw true) to the melting point of tungsten (3655°K) that the evaporation rate varies directly with ℓpw.

$$\text{Evaporation Rate} = 1.595 \times 10^{-18} \quad \ell pw^{8.30}$$

As a function of temperature:

$$\log_{10} \underset{(\text{gram} - \text{cm}^{2} - \text{sec}^{-1})}{\text{Evaporation Rate}} = 9.27 - \frac{45,670}{T°K}$$

As a function of temperature:

$$\ell pw = 1.36 \times 10^{-13} \quad T°K^{4.11}$$

It is also true that evaporation varies as approximately the 30th power of temperature.

The basic life assumption is that a lamp fails as a result of tungsten evaporating from filament and eventually reaching a critical weight loss with fracture occurring due to localized overheating of the filament. In addition, general data suggests that the critical weight loss varies with filament construction.

Filament Type	Critical Weight Loss in Vacuum
Straight Wire	16 - 22%
Single Coil	12 - 15%
Coiled Coil	2 - 3% (Gas Filled)

6.1 Characteristic Exponents

Since the lamp fails due to weight loss within some range, the lamp life can be equated to lamp characteristics. The socalled lamp exponents are calculated from the basic properties of tungsten.

$$\frac{\text{Life}}{\text{LIFE}} = \left(\frac{\text{LUMENS}}{\text{lumen}}\right)^{a}$$

$$= \left(\frac{\text{LUMENS/Watt}}{\text{lumens/watt}}\right)^{b}$$

$$= \left(\frac{\text{VOLTS}}{\text{volts}}\right)^{d}$$

$$= \left(\frac{\text{AMPERES}}{\text{amperes}}\right)^{u}$$

Typical Published Exponents are:

	Vacuum	Gas-Filled
a =	3.85	3.86
b =	7.0	7.1
d =	13.5	13.1
u =	23.3	24.1

Since life varies with ℓpw and volts, it is also true that ℓpw and volts have a relationship

$$\left(\frac{\ell PW}{\ell pw}\right)^{b} = \left(\frac{VOLTS}{volts}\right)^{d}$$

OR

$$\left(\frac{\ell PW}{\ell pw}\right) = \left(\frac{VOLTS}{volts}\right)^{g} \quad \text{and} \quad \frac{d}{b} = g$$

The typical Published Value of "g" is:

	Vacuum	Gas-Filled
g =	1.93	1.84

The most frequently used exponents are b and d. In the past, exponent "b" was thought to be a variable depending on temperature. However, more recent data shows "b" to have a fixed value of approximately 8.3 for perfect lamps.

Life is proportional to evaporation rate.

Evaporation rate varies with $\ell pw^{8.3}$

Therefore: Lamp Life varies with $\ell pw^{8.3}$

The "d" exponent is shown to be equal to the "b" exponent times the "g" exponent, or 8.3 g.

The "g" exponent varies with filament temperature and can be accurately determined by lamp measurements as follows:

1. Fully age sample lamps and measure ℓpw at rated volts.
2. Measure same lamps at proposed test voltage and record ℓpw value.
3. Calculate "g" exponent.

$$g = \ln\left(\frac{\ell pw \text{ at Test Volts}}{\ell pw \text{ at Rated Volts}}\right) \div \ln\left(\frac{\text{Test Volts}}{\text{Related Volts}}\right)$$

For example, a 100 watt, 120 volt, CC-8, A-19 lamp was found to have ℓpw values of 17.43 at 120 volts and 22.56 at 140 volts.

$$g = \ln\left(\frac{22.56}{17.43}\right) \div \ln\left(\frac{140}{20}\right) \qquad g = 1.67359$$

Therefore d = 8.3 x 1.67359 = 13.89 for life testing the 100/120 volt lamp at 140 volts. It is apparent that the value of g is not typically 1.84 and d is not typically 13.5 although the d exponent discrepancy is small in this example.

Historical data indicate the exponents are different depending on whether the lamp is vacuum or gas filled. This is misleading. The condition occurred because the test lamps evaluated were 10 ℓpw vacuum lamps

and 16 ℓpw gas filled lamps. The rate of evaporation is quite different for vacuum and gas filled lamps but the change in evaporation rate of tungsten at the same temperature to another temperature is the same. Gas filling (1 atmos) results in approximately 100 times lower rate of evaporation than in high vacuum.

It is possible to compile a universal table for exponent "g" when average filament temperature is known. Usually lamps are evaluated on measured lumens. By use of the table, the calculated "g" exponent is a good indicator of coil temperature. To use the table, measure ℓpw at two voltage levels no more than ± 5% from rated volts. When a large difference in voltage is used, the calculated "g" exponent will be an average for the two ℓpw levels which is desirable for life testing but not to indicate filament temperature.

Table I

Filament Temp. °K	"g" Exponent	"d" Exponent
2600	2.13	17.7
2650	2.06	17.1
2700	1.99	16.5
2750	1.93	16.0
2800	1.86	15.5
2850	1.81	15.0
2900	1.75	14.5
2950	1.70	14.1
3000	1.65	13.7
3050	1.60	13.3
3100	1.55	12.9
3150	1.51	12.5
3200	1.47	12.2
3250	1.43	11.8
3300	1.39	11.5
3350	1.35	11.2
3400	1.31	10.9
3450	1.28	10.6
3500	1.25	10.4
3550	1.22	10.1
3600	1.19	9.8

When "g" exponent is calculated as a function of the measured ℓpw of a lamp the following data is typical.

100 Watt CC-8

Volts	Measured ℓpw	"g" Exponent	Indicated Temp. °K
100	12.4	1.98	2710
110	14.89	1.87	2797
120	17.43	1.78	2875
130	20.05	1.67	2979
T-3 Linear Halogen Lamp			
160	32	1.42	3260

For approximate Conversion

$$g = 2{,}978{,}424 \; T°K^{-1.80}$$

OR

$$T°K = 4069 \; g^{-0.5974}$$

It has already been stated that the fatal weight loss for any filament type has a range of as much as 50% for coiled coil lamps. The range is due to coil manufacturing tolerances, wire defects, voltage fluctuation etc. When the theoretical "d" exponent is used it would be expected that the real world life tests would not be as calculated. To establish the life test factor, it is necessary to run lamps at the rated volts and also at test voltage and compare results with the theoretical values and then establish a fractional value of theoretical. The closer the fraction approaches 1.0, the better the lamp quality in all respects.

For example, 346 100 watt, 120 volt lamps were tested at 120 volts and and an average life of 698 hours. At 180 volts, life was 5.63 hours. The theoretical life should have been 934.58 hours based on bg = 12.6. The fractional value was $\frac{698}{934.58} = 0.7469$.

On this basis, lamp life varies as 0.7469 x (Force Volt Ratio $)^{12.6}$ for this lamp type. It would also be possible to restate as an actual "d" exponent

$$(\text{actual})\; d = \frac{\log\left(\frac{698}{5.63}\right)}{\log\left(\frac{180}{120}\right)} = 11.88$$

There are two problems of using only actual "d"

1. There is no indication of how close the failure mode approaches classic evaporation.
2. There is a tendency to use exponents for ℓpw vs life and voltage vs life that do not yield equal results.

The fraction decreases with lamp current. Although the d = bg calculation reduces all lamps to a common denominator (temperature), it does not account for more problems with small filament wire, notching, mechanical breakage, etc. Therefore, fractional values must be established by testing. Higher wattage lamps test closer to theoritical values because of higher temperatures and larger wire weights which have considerable more resistance to failure by notching, vibration, contamination, etc. It is for this reason that low voltage - high current lamps are superior to high volt - low current lamps.

6.2 Filament Mass vs Filament Compactness

Referring to the data on fatal weight loss, if a 100 watt, 17.4 ℓpw 120 volt lamp was designed as a straight wire, single coil and coiled coil the variation in filament mass would be as follows.

Straight Wire	11.688 mg
Single Coil	31.545 mg
Coiled Coil	34.96 mg

For the same life if all three filament types failed due to evaporation, the projected ℓpw values would be as follows:

Coiled Coil $\quad 17.4$ ℓpw

Single Coil $\quad \frac{31.545}{34.56} \times 17.4 = 15.7$ ℓpw

Straight Wire $\quad \frac{11.588}{34.96} \times 17.4 = 5.8$ ℓpw

In general, coiled coil lamps have approximately 5 - 20% higher efficiency than single coil lamps because of higher filament mass and lower gas loss especially in low wattage types.

The following table shows typical data for 240 volt lamps.

	Watts (240 Volt) 40	60	100	150
Single Coil ℓpw	8.5	10.17	12.3	13.73
Coiled Coil ℓpw	10.25	11.66	13.3	14.4
Ratio $\frac{CC}{Sc}$	1.21	1.15	1.08	1.05

It is obvious that for any wattage, the most efficient lamp is the one with the most compact high mass filament optimized for minimum filament temperature.

6.3 Lamp Life as a Function of Lamp Current

The following formulae can predict approximately the life vs ℓpw as a function of mount type and lamp current.

The type of mount and gas fill or vacuum is dictated by lamp current, coil geometry, sag, number of supports, etc. CC-8 mounts are most efficient in gas-filled lamps. Low current lamps (below .2 amps) are usually vacuum lamps with single coils.

CC-8 (With Center Support) Gas-Filled Lamps

750 Hour $\ell pw = 18\ I^{.25}$

CC-9 or CC-6 Gas Filled Lamps

1000 Hour $\ell pw = 16.498\ I^{.254}$

C-9 Gas Filled Lamps

1000 Hour $\ell pw = 15.54\ I^{.32}$

C-9 Vacuum Lamps

1000 Hour $\ell pw = 11.36\ I^{.157}$

6.4 Lamp Life as a Function of Burning Environment

Up to this point, discussion has been limited to filament, temperature, and filament mass as lamp life factors. The third factor is lamp burning environment. The environment is either vacuum or an inert gas. However, a perfect vacuum does not exist nor does 100% pure fill gas. On normal life test, nearly all short life failures are due to a contaminated burning environment. The contamination may come from many sources including fill gas, bulb, filament, support wire, leads, getters, etc. The harmful

contaminants are usually carbon, water vapor and oxygen. The effect of the contaminants is well documented, especially the water cycle and will not be discussed further. Detailed information can be found in the Incandescent Lamp Design and Manufacturing Handbook, by D. R. Dayton. For halogen lamp contamination discussion, refer to the Halogen Lamp Design and Manufacturing Handbook by D. R. Dayton.

6.5 Lamp Life as a Function of Lamp Material Defects

The fourth lamp life variable is lamp manufacturing defects and/or raw material quality. Smooth round tungsten wire is the best; uneven, cracked, nicked wire will result in early hot spots which will fail sooner than usual. Over clamping, loose clamps, uneven pitch, uneven coil stretch, poor tungsten chemistry, sagging, offsetting, etc. will all have some effect on the life of the lamp.

6.6 Lamp Life as a Function of Lamp Current Frequency

One last variable is current. Low current lamps have a shorter life on DC than AC. This usually applies to filament wire less than 1 mil. High current lamps have a longer life on DC than AC. The long life on DC is due to DC coil etching which occurs in all lamps vacuum or gas filled. The DC etching occurs earlier than AC etching and results in a reduction in coil temperature due to increase emissivity. Eventually AC etching is as rough as DC etching, but AC etching takes longer to develop. The result is a longer time at a higher temperature on AC than DC and therefore a shorter life on AC.

7.0 THE MAXIMUM INCANDESCENT LAMP

The purpose of an incandescent lamp is to convert electrical energy to luminous energy in visibile wave bands. There are many factors which have considerable bearing on the lumen -- life relationship of all types of incandescent lamps. The following factors must be optimized for the maximum incandescent lamp.

7.1 Lamp Wire - Mechanical

Studies have shown that the quality of lamp wire has a bearing on the time it takes to develop a hot spot which will eventually be the failure point.

Smooth round wire of a constant diameter and uniform chemistry is desirable. The wire must be free of wire drawing lubricants, carbides and have a uniform tensile strength, camber, etc.

This wire is best made by line etching to remove all surface contaminants and roughness at a diameter close to finish size. The wire may be oxidized and lubricated for final wire drawing. Expected life increase 10 - 30%.

7.2 Lamp Wire Chemistry

Contaminants are a major problem.

Tungsten contamination results in:

1. Brittlesness, due to the reduced ductility of the contaminated surface and consequent cracking of the tungsten due to its notch sensitivity.
2. Bulb Wall Darkening due to the higher evaporation rates of the contaminants.
3. Objectionable Sag due to an interstitial such as carbon, and the resultant tungsten carbide dispersed in the grain boundaries and within the grains.

Nickel, iron and moly are the most common contaminants in filament and cathode manufacture. All three of these elements are substitutional in nature; that is, they are diffused into the tungsten

lattice by substitution. The iron and nickel are incompatible with the tungsten, and form brittle second phases and intermetallics, which show up as small, equiax grains, the depth of which depend on the temperature and concentration of the contaminants.

Some of the chemical problems are in basic ingot and cannot be detected in lamp wire. Ingot tracing and approval is best insurance.

7.3 Primary Coil Winding

Mandrel

The best mandrel material is moly. The mandrel wire must also be smooth, round, clean and have uniform tensile properties. Control of size (diameter) is important because the mandrel diameter controls the length of filament wire used for a given number of turns at a given TPI. Sylvania type MO-71 is suggested.

Primary Coil Winder

The GTE Syl-coiler is suggested over the S-81 because of less stress put on filament wire.

Annealing

Annealing should be done in pure hydrogen bubbled through distilled water at 55°C or pure hydrogen with a small amount of pure CO added. The annealing temperature depends on design variables but is normally between 1200 - 1400°C for black tungsten wire and 1350 - 1600°C for cleaned tungsten wire.

7.4 Secondary Winding

Secondary winding is done on a retractable mandrel C-173 or a skip space 4-G Coil Winder. 4-G equipment is used when secondary mandrel is less than 10 mils.

There is an inherent problem with C-173 machines. When wire is wound around the mandrel, a twist is put in the wire. There is evidence that this stress builds up and makes the primary coiling turn over in the short distance between the wire guide and mandrel. The result is a hot primary section every 7 or 8 secondary turns.

This potential coil failure point can be detected by aging finished lamp and then taking a picture while a capacitor is discharged across the lamp.

The only way to eliminate this twist problem is to use a G-173 where primary coiling is fed normal to mandrel and then bent parallel to mandrel to form legs.

In addition to the coil winding process, the retractable mandrel is critical.

1. The diameter of the mandrel affects filament length and consequently must be accurately determined.
2. The mandrel should be round, since out-of-roundness affects filament length and promotes coil distortion.
3. The surface of the mandrel should be free of any imperfections which might score or otherwise damage the coil. Rusting (of steel wire) should be guarded against by proper storage before use. Mandrels used for automatic coiling processes require a bright smooth finish so the coils will not bind on stripping. Such mandrels may be polished by wiping lightly with crocus cloth, but care must be taken not to change the diameter.
4. The mandrel should be of correct hardness to render it best suitable for its particular application. Mandrels used for automatic coiling processes should be hard enough to prevent grooving or excessive wear, but not so brittle as to cause frequent breakage on the machine.

The amount of spring back at secondary winding (number of finished coil turns divided by number of machine turns) must be constant and/or allowed for in the coil design.

7.5 Secondary Coil Stress Relieving

The primary mandrel is left in the coils for stress relieving. This process is sometimes called sintering. The coils are loaded into clean moly boats and batch processed in wet pure hydrogen or

$H_2 + CO$ at temperatures in the range of 1100 - 1675°C. Pure hydrogen is required. Disassociated NH_4 is not recommended. Dry H_2 sintering is recommended after the wet H_2 sintering.

7.6 Primary Mandrel Removal

When dissolving Mo-mandrel, care should be taken that the reaction does not get out of control. Rather small quantities of coils should be treated separately. Coils must not be kept in the dissolving solution for a longer time than necessary to remove the mandrel.

Sufficient amounts of equal parts of nitric acid and sulfuric acid should be used to completely cover the coils. The coils are then boiled in a saturated solution of trisodium phosphate for fifteen minutes, rinsed thoroughly in hot tap water and dried. Coils are then given the coil etch process.

7.7 Coil Etch Process

1. Add six parts of concentrated nitric acid to three parts of water. Add this to ten parts of concentrated hydrochloric acid.
2. Add the mixed acids to the vessel containing the batch of coils and heat to a boil.
3. Boil for fifteen minutes. The time is critical as a percentage of weight of the coils is lost. At the end of this time, the coils and vessel will be coated with a yellow tungsten oxide.
4. Rinse the coils in ammonium hydroxide to remove the yellow oxide coating.
5. Rinse several times in hot tap water followed by a distilled water rinse.
6. Repeat steps 3, 4, 5.
7. Boil in distilled water for fifteen minutes.
8. Centrifuge the coils as specified.

NOTE: Coil etch process may require modification depending on coil wire size. Coil etch is done on 120V - 3 Watt (0.29 mg. wire) with a different schedule.

7.8 Filament Design

The requirements for the filament design are:

1. Compact design - low mandrel ratios.
2. Maximum wire weight - Maximum wire weight means minimum primary and secondary pitch. However, the minimum pin pitch must be 110%. In addition, the minimum permissable pitch is a function of the ability of the coil winding process to hold close pitch. The theoretical lamp life is proportional to wire weight but failure is due to a hot spot or weak link in the chain. Therefore, the maximum life coil design may not be the largest wire weight under real world manufacturing tolerances.
3. Low end losses and gradual temperature gradient.

The clamp is a heat sink and is very cold compared to the filament. The end loss is a matter of $Q = \frac{KA\Delta T}{d}$. Based on recent studies, the unwound filament leg length to wire diameter ratio should be approximately 500:1. The leg loss can be checked by raising the coil temperature and checking ℓpw. There should be a 11 - 12% rise in ℓpw for a 50° rise in coil temperature for GLS gas filled lamps. The gain will be 8 - 10% for high wattage lamps (above 1 amp lamp current).

The gradual temperature gradient is necessary to prevent notching of the filament wire especially on low current lamps. The material transport that results in notching is not well understood. In AC lamps a type of DC notching occurs near supports and clamps. The accepted mechanism is that tungsten has thermoelectric properties that cause a DC current to flow from hot to cold when there is a sufficient temperature gradient. The lower the lamp current, the more life loss due to a steep temperature gradient. Reduction of end losses will reduce the temperature gradient at the same time.

4. Optimized coil Design for minimum coil temperature for desired watts and lumens. This design will be evident when a slightly larger wire size and length results in wattage above specification and ℓpw below in a ration of about 1:3.

That is + 1% Watts and - 3% ℓpw which means that the lamp current cannot raise the filament to sufficient temperature.

7.9 Fill Gas Mix

The molecular weight of the fill gas should be as high as possible without arcing problems. The clean filaments will prevent most initial arcs. 100% Argon or Krypton cannot be used. The value of Kr increases with decreasing wattage and from coiled coils to single coils. Above 75 watts (120 Volts) Kr is not much better than Argon for reducing gas loss in gas filled lamps.

For high molecular weight, a gas mix of $72Kr + 8Xe + 20N_2$ is suggested. For 120 volt lamps, $82Kr + 8Xe + 10N_2$ may be acceptable. The higher the molecular weight of fill gas, the lower the tungsten evaporation rate and the longer the lamp life.

7.10 Fill Gas Pressure

The higher the fill pressure, the longer the lamp life and least tendency to fail due to arcing. The maximum fill pressure is a function of the hot operating pressure and the strength of the bulb.

It is not generally practical to have a tailored bulb size for each wattage, but it is reasonable to tailor fill gas pressure for each wattage for a given bulb size. A safe operating pressure for an A-19 is 1100 Torr. Based on wattage, the cold fill pressure of 40, 60 and 75 watt lamps should be:

Lamp Type	Cold Fill (Torr)
40	833
60	784
75	757
100	720

With the smaller bulb with Kr fill gas, the acceptable pressure can be even higher..

7.11 Bulb Size

The bulb size should be as small as possible. The size is limited by the following parameters.

1. Bulb temperature under lamp operating conditions - usually limited to a maximum of about 200°C for GLS lamps.
2. Mount geometry requires some neck size to insert mount without bumping problems.
3. Lamp burning environment may limit bulb size to prevent glass strain problems or bulb deformation (bulging).

There is good reason to make bulb as small as possible because the smaller the bulb, the stronger the bulb and often the least expensive bulb. The strongest bulb shape is a sphere. The bulb should have uniform glass thickness and be free of surface defects.

7.12 Leads

The most important property of the leads is they must be clean. They must be stiff enough to support mount during handling and shipping. They must be large enough to have little or no I^2R drop due to resistance heating. The material must be capable of being deformed during clamping and not open up during lamp operation and cycling. The present nickel plated copper is satisfactory. Pure nickel is also satisfactory. Moly is good as a material but poor for forming and clamping.

8.0 INCANDESCENT LAMP FLASHING

Flashing is the term used to describe the initial lighting of an incandescent lamp. The purpose of the flashing process is to clean the coil surface, and to recrystallize the tungsten into the proper high temperature interlocking structure needed for resistance to sag during its burning life. Usually it is the last step in the manufacturing process. Engineering specifications spell out the particular manner in which flashing is to be done for each lamp type. The procedure specified is called a flashing schedule. In some respects the flashing schedule varies considerably from one lamp to another. In general, it consists of the lamp being lit up on six stations on the finishing machine for roughly two seconds each time.

Initially, because of surface impurities on the coil volatilized into the gas at first heating, an incandescent lamp acts like a gaseous discharge lamp. When voltage is applied, the atmosphere in the lamp ionizes and becomes conductive. The current passing through the ionized atmosphere causes an arc. This arc tends to draw a very high current and becomes destructive unless it is limited by a resistor in the circuit. Consequently, the flashing schedule will normally specify the resistor and open circuit voltage to be used at each station. The final position has no ballast or series transistor, since by that time all volatile impurities have been removed from the coil.

8.1 Vacuum Lamps

Vacuum lamps are pumped down to a pressure of approximately 30 microns. To complete the job of evacuating the lamp a getter is used. The tungsten coil is coated with a phosphorous getter. During flashing, while the gaseous discharge arc is taking place, the getter evaporates and combines with the residual gas molecules. This forms a solid which deposits on the bulb wall. A momentary bluish glow becomes visible while ionization occurs. As the clean-up takes place, the glow will disappear, indicating no further presence of gas.

8.2 Gas Filled Lamps

Gas-filled lamps are filled with a mixture of high purity argon and high purity nitrogen. Usually the mixture is mostly argon. For example, the 60 watt GLS lamp contains about 94% argon, 6% nitrogen. Pure argon tends to ionize easily, promoting arcing. The addition of a small amount of nitrogen reduces the arcing tendency. The amount of nitrogen necessary to inhibit arcing depends on the lamp type. In general coiled coil types require more nitrogen than single coil types. Since nitrogen has a greater cooling effect on the filament than argon, it is desirable to use the least amount possible as long as arcing is avoided. The higher the argon ratio, the more efficient the lamp is in terms of lumens per watt for a given life rating. For this reason, lamps are produced close to the arcing threshold. Many gas-filled lamps, if not flashed according to the specified schedule, will arc when lit at rated volts. This is because of slight impurities present in the lamp atmosphere or coming off the coil. In such cases it is necessary to provide a ballast to limit the current for the first few seconds while a clean-up takes place.

In addition to the clean-up, another important result is obtained by flashing. An unflashed coil can be stretched out to straight wire, while a flashed coil is very brittle and will break if stretched. This is due to the change in crystal formation which takes place as the coil reaches a very high temperature, usually at approximately the lamp's rated voltage.

Flashing at too high voltage causes the coil to become very brittle, so that broken filaments occur in the normal handling that the lamps get in shipment. On the other hand, flashing too low results in sagging filaments. In a vertical filament lamp, sagging at flashing may cause close secondary turns in the lower part of the coil, which greatly shortens the life of the lamp. As a compromise, a flashing voltage is selected which keeps the filament ruggedness score just above the minimum acceptable, being sure that the amount of sag is not excessive.

In general, the problem of sag is confined to the initial droop occurring at flashing. Once the lamp is lit at rated volts, the filament

takes a "set" and will exhibit no further tendency to sag. In some cases, such as in the infra-red types a very high flash is necessary to set the filament. This is because in service the filament operates at a temperature below that required to set it.

In general, fine wires or low current lamps develop better mechanical properties if initial heating is slow; conversely, high current heavy wire lamps need a fast heat rise. Capacitor discharge flashing is used for some high current lamps. Contaminated or impropery cleaned filaments are a major cause of arcing during flashing. Delayed arcs are often caused by contaminated moly support wires since it takes a few seconds to heat the support wire sufficiently for clean-up after the lamp is energized.

9.0 INCANDESCENT LAMP AGEING OR SEASONING

When standard incandescent lamps containing tungsten filaments are lighted for the first time, at constant, rated voltage, there is a rapid increase in luminous output accompanied by a corresponding rapid decrease in current. Most of the change occurs within the first twenty minutes, but changes at a slower rate may continue for several hours. Typical changes during the first ten hours of burning of 100 watt A19 lamps of current manufacture show an increase of about 30% in luminous out-put and a decrease of 5 percent in lamp current and wattage.

For precise photometric work, lamps which are employed as standards must be first stabilized to avoid the effects of these early changes. The initial burning of the lamps is referred to as "seasoning."

The cause of the changes in lamps characteristic during the seasoning period (about 1% of rated life) is due to recrystallization of tungsten, smoothing of the wire surface and evaporation of contaminants and deposits from the wire.

Seasoning can be accelerated within limits by force seasoning by the same over-voltages as force or accelerated life testing.

Lamps made with clean wire become seasoned quicker and with less change from initial values than lamps made from contaminated wire or black wire which has not been cleaned sufficiently.

9.1 IES Guide to Lamp Seasoning

Most of the current IES measurement guides [1-3] are vague when discussing the seasoning of lamps to be used in photometric, colorimetric, and electrical tests. The Testing Procedures Committee has prepared this report to provide the needed, more specific guidance on lamp seasoning, including forced seasoning to reduce testing time for certain lamps.

Introduction

Objective

This approved method provides a guide that will promote uniform seasoning of lamps intended to be used for measurement of photometric, colorimetric or electrical characteristics. Lamps should be seasoned until those characteristics remain constant during the test to be conducted.

Scope

This approved method will apply to incandescent, fluorescent, high intensity discharge (HID) and glow lamps. The seasoning schedule for a new type lamp should be similar to a listed type with which it most closely agrees.

Suggested Seasoning Schedule

Incandescent Lamps

This category will consist of most filament lamps having self-emission of radiant energy in the visible spectrum due to thermal excitation. It will include both gas filled and vacuum lamps. It will serve to indicate forced seasoning required for photometry when time does not permit the recommended burning of one-half to one percent of rated life at rated volts. It is preferable to overseason a lamp rather than to underseason it. On range voltage lamps, use center voltage for calculation. Unless otherwise specified, lamps should be seasoned in their base up position.

General Lighting Service

To include lamps of 100 to 135 volt circuit voltage having a wattage up to 1500.

1. 0 to 999 rated hours, season 45 minutes at 115 percent of rated volts.
2. 1000 rated hours and over, season at 120 percent of rated volts for one-half hour per each 1000 hours of design life or portion thereof.

Extended Service Lamps - Same as general lighting service.

Rough Service or Vibration Service Lamps

Season 45 minutes at 115 percent of rated volts.

Silvered Bowl Lamps - Same as general lighting service lamps.

Three-Light Lamps

Season at 115 percent of rated volts for 60 minutes with both filaments burning.

Tungsten-Halogen Lamps

Season one percent of rated life at rated volts.

Miniature-Subminiature Lamps

1. Flashlight

   Less than ten hours rated life, season five minutes at 100 percent of rated volts.

   11 to 20 hours, season ten minutes at 100 percent of rated life.

   30 to 59 hours, season 25 minutes at 100 percent of rated life.

   76 to 100 hours, season 30 minutes at 110 percent of rated life.

   101 to 150 hours, season 30 minutes at 115 percent of rated life.

2. Aircraft Lamps

   Season 28 volt lamps 20 minutes at 115 percent of rated volts.

3. Automotive Lamps

   Season at design volts for 20 minutes.

Multiple Street Lamps - Same as general lighting service lamps.

Series Street Lamps

Season at 100 percent of rated current for four hours. Make frequent checks of current setting to correct drift.

Traffic Signal Lamps

Season at 115 percent of rated volts for one hour.

High Voltage Lamps (200 to 300 Volts)

1. Less than 200 watts, season 45 minutes at 115 percent of rated volts.
2. More than 200 watts, season 90 minutes at 115 percent of rated volts.

Aircraft Lamps (100-125 volts)
Same as general lighting service lamps.

Showcase Lamps - Same as general lighting service lamps.

Bipost and Prefocus Lamps (Except Photographic)
Same as general lighting service lamps.

Airport and Airway Lamps (Except Halogen)

1. Season current type lamps at 110 percent of rated current for one hour per 1000 hours of rated life or portion thereof.
2. Season voltage type lamps same as general lighting service lamps.

Reflector Lamps (Spot, Flood and General)
Season at 115 percent of rated volts for one hour for each 1000 hours of rated life or portion thereof over 1000 hours.

Par Lamps - Same as reflector

Photoflood Lamps - Season five minutes at rated volts.

Photographic Lamps (Except Halogen)

1. T-Bulb Lamps

   10 hour lamp, season 6 minutes at rated volts.
   15 hour lamp, season 10 minutes at rated volts.
   25 hour lamp, season 15 minutes at rated volts.
   50 hour lamp, season 10 minutes at 110 percent of rated volts.
   200 hour lamp, season 20 minutes at 115 percent of rated volts.
   300 hour lamp, season 30 minutes at 115 percent of rated volts.
   500 hour lamp, season 45 minutes at 115 percent of rated volts.

2. Internal Reflector Lamps

   75 hour lamp, season 30 minutes at 108 percent of rated volts.
   500 hour lamp, season 2 hours at 108 percent of rated volts.
   1000 hour lamp, season 4 hours at 108 percent of rated volts.

Fluorescent Lamps.

A fluorescent lamp is a low pressure mercury electric-discharge lamp in which a fluorescent coating (phosphor) transforms some of the ultraviolet energy generated by the discharge into visible light. No satisfactory method has been devised by which a fluorescent lamp may be force-seasoned. Season in a horizontal position at a 3-hour on, 20-minute off cycle. The hot pin must be identified for both seasoning and photometry to prevent variations. Both hot and cold cathode lamps must be operated on a suitable ballast which complies with the ANSI specification for 100 hours at rated line volts prior to making any measurements. High current-density lamps such as the 1500-milli-ampere lamps may require special techniques even after 100 hours to maintain stability.

High Intensity Discharge (HID) Lamps

HID lamps are a general group of lamps consisting of mercury, metal halide metal vapor and sodium lamps. All lamps in this group must be seasoned for 100 hours using the recommended ANSI specified auxiliary ballast, operating at rated line volts. Lamps should be seasoned in the same position in which they are to be tested. The higher potential leg should go to the same eyelet contact in the socket for seasoning and testing.

Ultraviolet Lamps

Season UV (ultraviolet) lamps in accordance with the recommendations of the manufacturer.

Xenon Lamps (Short Arc)

Season a short arc xenon lamp as specified by the lamp manufacturer.

Reprographic Lamps - Season the same as HID sources.

Glow Lamps

In general, this is a group of neon or LED (light emitting diode) type lamps. They should be seasoned in accordance with the recommendations of the manufacturer.

REFERENCES

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2. Testing Procedures Committee of the IES, "IES approved method for life testing of high-intensity discharge lamps," IES LM-47, JOURNAL OF THE ILLUMINATING ENGINEERING SOCIETY, Vol. 4, No. 1, October 1974, p. 66.

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10.0 INCANDESCENT LAMP TESTING

10.1 IES APPROVED METHOD FOR ELECTRICAL AND PHOTOMETRIC MEASUREMENTS OF GENERAL SERVICE INCANDESCENT FILAMENT LAMPS

Foreword

This guide is one of a continuing series of IES Approved Methods being prepared to create a greater uniformity of photometric measurements and reporting among various laboratories. The material covered here was developed to provide a uniform method for photometric and electrical measurements for data now required on certain incandescent filament lamps.

Introduction

General

This guide describes the procedures and precautions to be observed in the photometry of general service incandescent filament lamps to obtain reliable measurements which can be duplicated in different laboratories performing the same task under substantially the same controlled conditions.

Scope

Incandescent filament lamps, as covered by the guide, produce radiation in the visible portion of the electromagnetic spectrum as a result of passing current through a tungsten filament, surrounded by an inert atmosphere or vacuum in a glass envelope. The measurements that are normally made in lamp photometry are luminous flux, intensity and electrical characteristics. In addition, luminance measurements are sometimes required.

Details not covered in this guide may be found in the "IES General Guide to Photometry,"[1] "IES Practical Guide to PHotometry,"[2] "Photometry"[3] by J. W. T. Walsh, and other suitable references.[4-10] Excluded from this guide are such types as reflector lamps which are covered in other guides.[7]

It is often important to know the life along with the light output and electric characteristics of incandescent filament lamps. For such information, refer to the "IES Approved Method for Life Testing of General Lighting Incandescent Lamps."[4]

This guide also describes electrical and photometric testing of incandescent filament lamps and how these tests are related to life test and lumen maintenance data:

1. Electrical testing consists of measuring amperes and volts, with one or the other held constant, thereby allowing calculation of watts.
2. Photometric testing consists of measuring the light output (flux or intensity) of individual lamps. Flux measurements allow calculation of efficacy.
3. Life testing consists of operating lamps at controlled voltage or current and noting starting and failure times.
4. Lumen maintenance data are obtained by photometry at certain operating time intervals (specified percentages of rated life).

Nomenclature and Definitions

1. Units of electrical measurement are volts, amperes and watts.
2. Units of photometric measurement are lumens (luminous flux), mean spherical candlepower (flux) or candlepower in a specified direction (intensity).
3. Seasoning refers to the time required for operating of an incandescent filament lamp to obtain sufficient tungsten recrystallization for the electrical stability needed for photometric or electrical testing.
4. Regulation refers to constance of voltage or current applied to the lamp during test.
5. Multiple lamps (those rated by wattage or voltage and operated directly across a supply line) are those normally tested at constant voltage, and series lamps (those rated by amperes and operated in series across a supply line) are those normally tested at constant current.
6. Standard cell refers to an emf standard (normally unsaturated) used as a reference in conjunction with precision potentiometers, which in turn are used to measure DC voltage and current.
7. Secondary lamp standards are lumen or candlepower standards derived from the primary national standard and are used to establish working standards, which in turn are used to calibrate photometers.

Test Conditions

General

The environment in which lamps are to be tested is most important to the reliability of test results.

Temperature

Temperature constancy is one of the most important environmental considerations. Most of the equipment used for photometry and electrical tests will measure repeatably at any given temperature between +4°C and +40°C, but corrections to standard conditions may be required. If corrections are necessary they should be made in accordance with the instrument manufacturer's recommendations. To avoid making these corrections, standard temperature conditions should be 20° ± 1°C.

Vibration

Vibration may cause electrical lamp instability and instrument errors, and may cause premature lamp failure because of filament brittleness. Therefore, vibration should be kept to a minimum in the test equipment, and extreme care should be exercised in the handling of both unlighted and lighted lamps.

Extraneous Light

Extraneous light will affect all photometric measurements. To overcome this problem it is necessary in the case of lumen measurements to mount the lamp in an enclosure, such as an integrating sphere; or in the case of candela measurements, the lamp should be mounted in a dead (non-reflecting) enclosure, or in a completely flat-back room using baffles.

Power Supply

Type of power supply to be used depends upon the type of testing to be done, as follows:

1. Series lamps require either a constant current source, or a constant voltage source, depending on individual requirements.
2. Multiple lamps are normally tested on direct current at rated voltage. A DC supply with a regulation of 0.1 percent or better and a ripple content not exceeding 0.4 percent of the output voltage is required in this case.
3. It may be desirable or necessary to test multiple lamps on alternating current. The AC power supply should have a voltage wave shape

such that the rms summation of the harmonic components will not exceed three percent of the fundamental. If the static type of voltage stabilizer is used, it is of particular importance to check the wave shape. The line voltage should be as steady and as free from sudden change as possible. For best results the voltage should be regulated to within ± 0.1 percent. If adequate automatic regulation is not available, constant checking and readjustment are essential if accurate measurements of lamp characteristics are to be obtained. Where the AC line regulated supply distorts the wave shape, it is necessary to use a thermocouple or dynamometer-type AC meter. In the latter case, the current drawn by the meter must be taken into account.

Equipment and Instrumentation

Instruments

For selection and care of instruments used in electrical and photometric testing, see "IES Guide for the Selection, Care and Use of Electrical Instruments in the Photometric Laboratory."[5]

1. The analog-type voltmeters, ammeters, and wattmeters used in testing should have an accuracy of at least 0.25 percent of full scale deflection. All AC instruments must be compatible with the wave shape existing at the test location to indicate true rms values.
2. Ditigal voltmeters and ammeters have advantages in accuracy, speed, and direct read-out, eliminating many sources of error.
3. Recording instruments may be used to record the stability of a power supply and the candlepower distribution on a goniometer.
4. Photoelectric detectors and instruments generally consist of a color- and- cosine-corrected photovoltaic cell or a phototube. The detectors are connected to a null-balance instrument, an indicating microammeter, galvanometer, an operational amplifier, or digital readout devices. Because of the detector's temperature dependency it may be necessary to apply appropriate corrections to the readings obtained.

Photometric Equipment

There are three types of photometric equipment in general usage: the integrating sphere, the goniometer and the bar photometer. For convenience, electrical measurements may be made on any of these photometers just prior to the reading of lumens or candelas.

1. Luminous flux (lumens) or mean spherical candlepower, is determined with an integrating photometer. Care should be exercised in selecting an integrating photometer of suitable size for the physical size of the lamp being tested, since the ratio of the volume taken up by the lamp and lamp holder to the total volume of the sphere should be as small as possible. However, the sphere should be sufficiently small to obtain a minimum of two footcandles (2.2 dekalux) of incident light on the photovoltaic cell. The sphere should be properly painted inside and contain a baffle between the lamp and detector. If the lamp being measured is a different size or color temperature than the standard used to calibrate the sphere system, a color correcting filter should be used immediately in front of the detector.
2. Candlepower distribution is determined with a goniometer. The goniometer provides means for changing the vertical and horizontal angular relationships between the photocell and the photometric center of the lamps. It must accurately indicate the photocell viewing angle while maintaining constant lamp to photocell distance. The photometric center of rotation of a clear glass lamp should be the center of the filament. The photometric center of a frosted glass lamp should be about the center of the glass envelope.
3. Candlepower (luminous intensity) is determined with a goniometer or bar photometer. The bar photometer provides a direct comparison between the test lamp and the working standard.

Selection of Test Lamps

Test lamps should be representative of the lot from which taken. The value of the test will depend upon the method of sampling, size of sample, conditions of testing, and many other factors. The effects of such variables are discussed in "Experimental Statistic,"[6] Handbook 91, issued by the National Bureau of Standards.

Pretest Procedures

Handling and Storage

The lamps should be handled, transported and stored in such a way as to minimize the effects of vibration and shock on the filaments.

The lamps should not be subjected to high humidity conditions as this could weaken the cememt bond between base and bulb or cause corrosion of the metal base shell resulting in high resistance and inaccurate electrical measurements.

Storage should be in a relatively clean atmosphere so as to eliminate the effect of dirt on light output, It is necessary to clean lamps prior to and after photometry to eliminate handling marks.

Identification

Lamps should be marked for identification with numbers or letters around the neck of the bulb. Care should be taken to use marking ink (preferably black) that will not fade and will be heat resistant so that identification is not lost during the life test. Lamps used for horizontal candlepower measurements should be marked or etched to show which is the sensor side and the direction of calibration.

Lumen Maintenance Data

If lumen maintenance data are required, the life periods at which lamps are to be photometered should be determined. The most commonly accepted periods are after seasoning, at 35 percent rated life and at 70 percent rated life; however, other or additional points may be selected to meet the particular need.

Initial Photometry

Lamps which are to receive their initial photometry should be seasoned for at least 0.5 percent of rated life at rated volts, or rated current, or correspondingly shorter times for higher than rated volts or current.

Stabilization and Calibration of Equipment

When a detector is used, the first and foremost precaution is to make certain that the detector(s) has been fatigued. Failure to do so will result in unreliable data.

The next step is to perform the necessary calibration procedures such that the reading of the detector response will be a true indication of light output. Working standards are normally used for this purpose. It is recommended that at least three working standards be used to calibrate the system, and the average of the values at the time of standardization compared to those at the time of calibration be used to determine a correction factor. Rechecking should be made with sufficient frequency to assure a constantly uniform calibration.

All equipment used for measurements must be stabllized according to the manufacturer's recommendations.

Observation, Recording and Computation

All pertinent data required on the test report should be recorded as observed with any necessary corrections made and so indicated.

Test Report

Test reports should include pertinent items of the following data:

1. Date of test report
2. Number of lamps tested and sampling procedure used.
3. Description of lamps.
4. Description of equipment.
5. Description of standards used.
6. Life, electrical and output rating of lamp.
7. Intervals of measurements.
8. Special test conditions -- operating position.
9. Corrections applied.
10. Computations made (watts if measured on DC).
11. Candlepower distribution curve (if applicable).
12. Actual electrical and output readings.
13. Lumen maintenance and efficacy computations.
14. Statistical analysis.

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10.2 Incandescent Lamp Life Testing

10.2.1 Calculation of Average Life

Life tests of incandescent lamps are divided into two classes:

A. Rated voltage - normal testing

B. Over-voltage - forced life testing.

For A, rated voltage tests, lamps are operated at rated voltage in a specified burning position on a life test rack. The voltage should be regulated to $\pm$ .25%.

For B, Over-voltage test, lamps are operated at a voltage above rated volts and normal life is calculated using lamp performance data. The lamp must not be "overforced" to result in explosions or lamp fill contamination.

Life test data is used to compute rated life of incandescent lamps. In United States, there are two ways of computing rated life.

1. Burn all lamps in a group until all have failed. Sum up total burning hours of all lamps and divide by number of lamps on test. This yields average life or rated life.
2. Burn all lamps in a group until the point is reached where 50% have failed and 50% are still burning. This point is called rated life.

In Europe and some South American countries, life test calculations are specified by the International Electrotechnical Commission (IES) Publications 64.

10.3 Force Testing

10.3.1 Analyzing the Life Test Data

The following is actual reported life test data for 36 watt, 228 volt, 1000 hour, 415 lumen rated lamps.

273 Volt Test

Lamp #	Amps.	Watts	Lumens	ℓpw	Life
1	0,165	37.6	438	11,64	77.0
2.	0.165	37.6	445	11.83	83.3
3	0,166	37.8	444	11.73	104.3
4	0.168	38.3	458	11.96	73.1
5	0.168	38.3	446	11.64	83.3
6	0.168	38.3	443	11.57	90.4
7	0.169	38.5	464	12.04	68.7
8	0.165	37.6	430	11.43	110.0
9	0.169	38.5	457	11.86	74.9
10	0.166	37.8	451	11.92	80.1
Average	0.167	38.1	448	11.76	84.5 hours

228 Volt Test

1	0.167	38.1	435	11.42	889
2.	0.169	38.5	450	11.68	1051
3	0.166	37.8	439	11.60	1211
4	0.167	38.1	453	11.90	1165
5	0.164	37.4	433	11.58	820
Average	0.167	38.0	442	11.64	1027 hours

At this point, the question of why the lumens are greater for the force test lamps than the normal test lamps is not clear. For a common group divided for normal and force test, there is every reason to expect average lumens in both groups to be equal.

The lamp list should be presented with the lamp test data in order of ℓpw beginning with the highest test lamp.

273 Volt Test

Lamp #	Amps	Watts	Lumens	ℓpw	Life
7	0.169	38.5	464	12.04	68.7
4	0.168	38.3	458	11.96	73.1
10	0.166	37.8	451	11.92	80.1
9	0.169	38.5	457	11.86	74.9
2	0.165	37.6	445	11.83	83.3
3	0.166	37.8	444	11.73	104.3
5	0.168	38.3	446	11.64	83.3
1	0.165	37.6	438	11.64	77
6	0.168	38.3	443	11.57	90.4
8	0.165	37.6	430	11.43	110.0
Average	0.167	38.1	448	11.76	84.5 hours

228 Volt Test

4	0.167	38.1	453	11.90	1165
2	0.169	38.5	450	11.68	1051
3	0.166	37.9	439	11.60	1211
5	0.164	37.4	433	11.58	820
1	0.167	38.1	435	11.42	889
Average	0.167	38.0	442	11.64	1027 hours

The first observation is that in the force test there is a general increase in life as ℓpw decreases. By discarding the obvious lamps that don't fit, the relationship between ℓpw and life can be calculated.

Life varies with $\ell pw^{-7.89}$ (Force Test)

$b = 7.89$

The average overall life of 228 volt test is 1027 hours and force test 84.5 hours. The average "d" exponent can be calculated as follows:

$$d = \frac{\log\left(\frac{228 \text{ volt life}}{273 \text{ volt life}}\right)}{\log\left(\frac{273 \text{ volts}}{228 \text{ volts}}\right)}$$

$$d = \frac{\log\left(\frac{1027}{84.5}\right)}{\log\left(\frac{273}{228}\right)} = \frac{\log(12.15)}{\log(1.2)} = 13.69$$

Now with exponents "b" and "d" defined, the force test data can be restated to indicate expectedlife and ℓpw at 228 volts.

Force test date restated for rated ℓpw of 11.53

Lamp #	ℓpw	Life	Life at Design ℓpw (11.53)
7	12.04	68.7	96.6
4	11.96	73.1	97.6
10	11.92	80.1	104.14
9	11.86	74.9	93.58
2	11.83	83.3	102.0
3	11.73	104.3	119.5
5	11.64	83.3	89.8
1	11.64	77	82.99
6	11.57	90.4	92.9
8	11.43	110	102.7
Average	11.76	84.5	98.8 hours

Restated for life at 228 volts at design ℓpw of 11.53

Lamp #	ℓpw	Life
7	11.53	1172
4	11.53	1184
10	11.53	1263
9	11.53	1135
2	11.53	1237
3	11.53	1449
5	11.53	1089
1	11.53	1006
6	11.53	1127
8	11.53	1246
Average	11.53	1198 hours

The 228 volt data supports this data. Average is 11.64 ℓpw at 1027 hours life. The 228 volt data shows no correlation between ℓpw and life, therefore no ℓpw at design life or life at design ℓpw can be calculated with any confidence.

The force test data indicates that life will vary from 1089 hours to 1246 hours for lamps at rated ℓpw - a swing of 15%.

Values of "d" exponent greater than theoretical should not be expected. When large "d" values are calculated it is because force life is short due to an imperfection in the lamp caused by over voltage. Conversely, an abnormally low "d" results from normal force life and short normal life due to water cycle or some other complication.

The conclusion of this life test force data is that most all of the lamps in the test lot will meet rated life at design ℓpw.

10.3.2 Force Testing of Lamp Lots Without Rated Volt Test Data

In production many lamps are force tested and few lamps tested at rated volts. Therefore, the accumulated data does not represent force and rated volt data from the same lamp lot. Under these conditions a running tally is scrutinized for dips and peaks which are indicitive of long and short lamp life.

It is fundamentally necessary that some basic data is required from a good lamp lot tested at rated and force volts. From then on, the force data must be examined to see if the ℓpw vs force life exponent is normal (7-8). Under these conditions, the projected rated volt-life can be calculated using the "d" exponent caculated from average force and normal life in original sample. A comparison of the actual "d" exponent and the theoritical d=bg exponent is useful to see how close the failure hours relate to expected failure from tungsten evaporation only.

10.3.3 Life Test Precautions

The life test data must be carefully gathered and accurate. The analysis of the data must be creditable. Lamps which do not form a mathematical pattern cannot be projected mathematically. The longer lamp life the more it is likely to fail due to a cause other than filament evaporation. No ℓpw at design life or life at design ℓpw calculation can be made at rated volts for GLS lamps unless the data can first be shown to conform to the exponents used.

It has become standard to use a "b" exponent of 7 for all calculations of ℓpw/dl. This is not valid unless the ℓpw and life data for that group has such a relationship. In addition, "b" and "d" exponents must give equal predictions. That is:

$$\left(\frac{Lpw}{\ell pw}\right)^{b} \quad \text{must equal} \quad \left(\frac{Volts}{volts}\right)^{d}$$

otherwise the life predictions at rated volts are meaningless.

10.3.4 Theoretical "d" Exponent

The life test data did not contain the ℓpw at force volts. This data is required to calculate the "g" exponent. Since d=bxg, the calculations using the "b" exponent must be equivalent to those using the "d" exponent. The indicated "g" exponent in this example is

$$g = \frac{d}{b} = \frac{13.69}{7.89} = 1.735$$ or a filament temperate of approximately 2900°K. Since the "g" exponent varies with filament temperature, the same "d" exponent cannot be used at all force voltages. However, the "d" exponent at any usable force voltage can be calculated by first determining "g" exponent.

For example, a 100 Watt, 120 Volt lamp measured 1786 lumens at 120 volts, 2926 lumens at 140 volts and 4400 lumens at 160 volts.

Volts	ℓpw	g
120	17.76	--
140	22.925	1.6519
160	28.05	1.5887

"d" at 160 volts is 4% less than "d" at 140 volt force. This would result in about a 16% difference in life calculations.

10.4 Additional Incandescent Lamp Tests

Overnight Age and Rotary Bump Test or OARB

The OARB test is a measure of the ability of the coil and mount to withstand cold shock and vibration. The lamps are lifted and dropped by the rotary motion of a notched drum. A special piece of equipment known as the Michigan Rotary Drum Tester is required. Lamp failure is checked by a continuity meter.

Variable Drop Test

The variable drop test is run with the lamp unlighted. The lamps are dropped from heights of 9, 16, 25 and 49 inches respectively. The lamps are dropped once from each height until failure. Failure is checked by a continuity meter.

Vibration Test

This test is for rough service lamps and vibration service lamps. Test lamps are not seasoned. Lamps are burned at rated volts. The frequency of vibration is 28.5 - 30.5 vibrations per second. The amplitude is 10-13 vibrometer scale units.

Vibration and Pendulum Bump Test

This test is a vibration and cold shock test performed on appliance lamps. The equipment consists of a rack suspended on springs to isolate it from external vibrations. The rack is bumped by a molded rubber socket suspended in pendulum fashion on a light chain 54 inches from point of suspension. Lamps are alternately bumped and vibrated until failure.

Hot Shock Test

This test covers rough service lamps tested to meet Naval Shipboard use specifications.

Puff Test for Detection of Oxygen

Lamps are run at low voltage for a short time and then examined for oxidized coils or a puff of smoke (tungsten oxide evaporation) when lamp is brought up to rated voltage.

Torque Test for Lamp Bases

This test is to check absence of basing cement, uncured cement, overcured cement or improperly mixed basing cement. The lamps are tested by applying a torque to the base. The minimum torque the base must withstand

before breaking loose from the bulb is specified. See GTE Sylvania Specification #2E0404-711-712A and Specification #2E0300-6.

Cyanogen Test

The cyanogen test is a method of detecting the presence of oxygen as a contaminant in sealed and exhausted gas-filled lamps. The principle of operation is that very small amounts of oxygen will suppress the radiation from a cyanogen radical (CN) molecular system. Accordingly, in a transparent sealed envelope such as an incandescent lamp, containing a source of cyanogen, an accurate indication of the amount of oxygen can be obtained by exciting the atmosphere in the bulb by high frequency radiation (a Teslar coil) and measuring the intensity of radiation of the cyanogen radical molecules.

Cyanogen is normally formed by reaction between carbon in the filament and nitrogen in the fill gas. It is destroyed by collision with molecular oxygen, forming CO and NO. Thus the ratio of the intensity of CN molecular emission to N_2 molecular emission provides a measure of the concentration of molecular oxygen in the lamp atmosphere Thereby, lamps can be rejected which are indicated to have excess oxygen as compared to a measurement or signal of a known reference lamp.

Base Electrical Test

For safety and convenience the lamp leads are soldered to the cap, which, for normal lamps - is either:

an Edison cap (base), i.e., a screw cap, or

a Swan cap, i.e., a bayonet cap.

In the Edison cap there is one center contact and the cap shell serves as a second contact; in the Swan cap there are two end contacts and the cap shell is dead.

In the Edison cap the center contact is connected to 120 or 220 volts and the cap shell is connected to the neutral line = earth (ground) this being a requirement for the installation. In the Swan cap one contact is connected to 220 volts and the other to earth (ground).

The contacts (i.e., center contact and shell of Edison cap, or the two contacts of Swan caps) must be separated by a very good insulator. The insulator is usually glass which has a high insulation resistance.

If a Swan contact or the center contact of the Edison cap is not insulated adequately from the cap shell, the insertion of a new lamp may be very dangerous: if the shell is touched during its insertion into a live holder, one will get an electric shock. Frequently, the electrician is standing on a ladder and this increases the risk.

The circuit tester (megger) would reject these lamps because it would register too low a resistance. B.S.I. specifications demand a minimum of 50 megohms between contacts and shell under specific (dry) conditions. A Swan cap is safer than an Edison cap because the Swan cap shell is never alive. Swan caps are used in the United Kingdom and all English speaking countries except the United States and predominantly in France. The Edison base is standard in the United States, Canada and several South American countries.

STANDARD METHOD FOR DESIGNATING NATURE AND POSITION OF FAILURE OF TEST LAMPS

Most failures of lamps are of the burnout or arc variety with an occasional failure due to handling.

Description of Failure	Designation
Burn Out	BO
Arc Fuse Burned Out	Arc PG
Two-lead arc, chipped or cracked press	Arc CP
Cold Bump	CB
Rotary Bump	RB
Lead Broken	LB
Broken Filament	BF
Broken Filament due to handling	BFH
Turn-on Failure	TO

11.0 QUALITY ASSURANCE OF INCANDESCENT LAMPS

Several faults can be found simply by visual inspection. Certain other faults can be found by measurements.

11.1 Pumping and Gas-Filling Defects

Pumping and Gas-filling quality can be assessed only by

a. The judgement by high frequency coiling the lamp

b. The cyanogen test

c. The judgement after lamps have been aged for one hour at 120% rated volts

d. The design life test performance

Vacuum lamp quality is assessed by high frequency coiling and by the ability of the lamp not to flash over (arc) when switched on at 120% of rated volts.

11.2 Visual Defects

Uncut wire or wires (serious fault - uncut wires can short on shell of base. Chance of making shell "live" on some type bases.)

Unsoldered or poorly soldered bases

Crooked bases

Poor etch or stamp

Damaged base

Tilted mount

Filament out of support

Crooked bulb

Loose Base

Solder in stem tube

Poor coating (smoke coatings, etc.)

Yellow lamps (excess Phosphorous getter)

11.3 Measured Defects

Wrong L.C.L. (measured with gauge)

Wrong M.O.L (measured with gauge)

Wrong diameter

The high frequency current is produced by means of an oscillating valve (B1) and HF coils (S1), (S2), (S3). The heater supply for the valve is taken from the transformer (T2) which has a center tapping. The anode current is supplied by transformer (T1). When the complete primary winding is in circuit, a spark length of 1.5 cm is obtained. When one-half of the primary winding is in, a spark length of 3 cm will result.

The terminal block for the connections for both spark length is placed before transformer (T1).

Coil (S2) is in the anode circuit. Coil (S1) is in the grid circuit.

When a voltage is applied to the anode, coil (S2) will create a voltage in inductances (S1) and (S3). Inductance (S3) has a self capacity which is in paralled with it, thus forming an oscillatory circuit, which will start oscillating in its natural frequency.

The oscillation is maintained as follows:
The oscillation is induced into inductance (S1) by means of its coupling to inductance (S3), and is amplified by the valve. This will continue until the anode voltage has decreased to such an extent as to stop the oscillations. In the following cycle the same process is repeated.

The grid and anode circuits of valve (B1) might start generating in their own frequency which is higher than the frequency of the inductance (S3). In order to prevent this, resistance (R1) and capacitor (C3) in series with each other are connected across the grid leak (R3-R4). Resistance (R4) is adjustable. Consequently, the oscillation, having a higher frequency than the normal one, is stopped. The voltage thus fed back to the grid circuit will cause such losses of energy in resistance (R1) that no generating conditions can be maintained for this frequency. In order to prevent parasitic oscillations through wiring capacities and inductances, a blocking resistance (R2) has been placed before the grid. Blocking capacitor (C1) prevents HF currents entering transformer (T1) A 315 mA fuse (V) is included in the anode circuit.

The Apparatus is connected to 240V A C supply mains via hook switch (Ak2) and 2 way switch (SK1). When the hand electrode is hanging on the hook switch (SW2), transformer (T1) is dead.

When the hand electrode is removed from hook switch (SW2), the strength of field of coil (S3) increases. Unless the coil is loaded, this would cause brushing of the coil and the production of creepage paths in the insulation

to the housing (earth). This is prevented by making the last winding of coil (S3) of wire much thicker and fitting a spark gap, which will arc over when the voltage becomes excessive. The spark gap consists of a brass globe connected to end of coil (S3) and is plugged into the bush in the center of the insulating plate opposite the globe. There is a bracket spaced at 32mm over the globe.

The length of spark may be varied by adjusting the secondary voltage of transformer (T1). This can be done by varying the transformation ratio (switching from 1.5 to 3 cm spark) or by adjusting the primary voltage by the insertion of a regulating transformer (T3) in series (see Figure 2).

HIGH FREQUENCY COIL

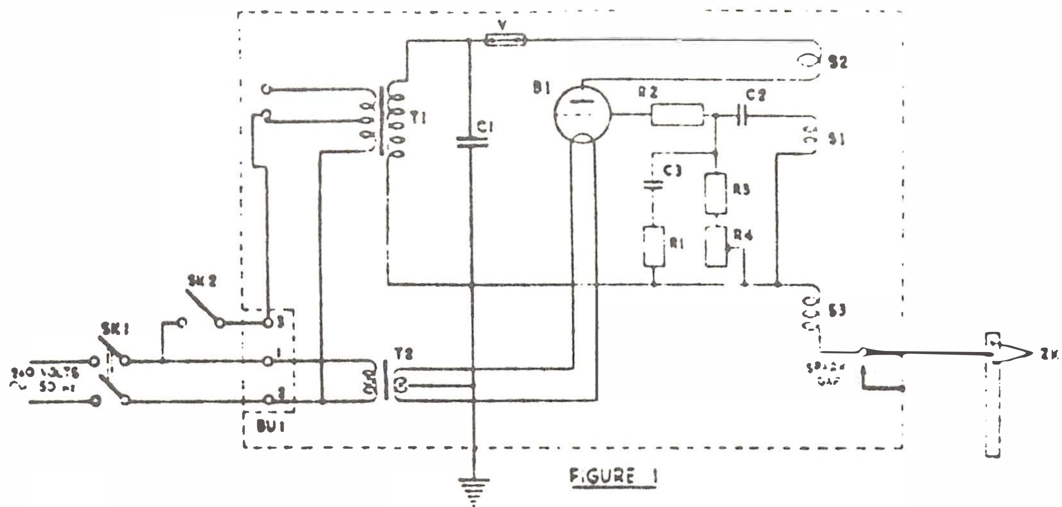


FIGURE 1

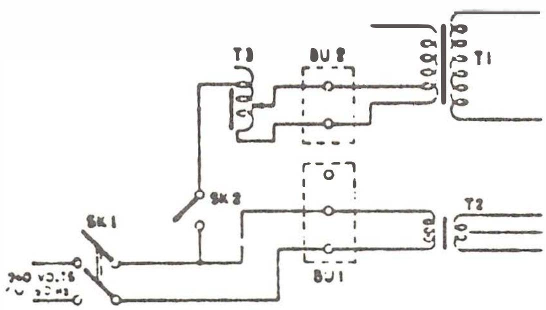


FIGURE 2

SYMBOL	DESCRIPTION	PART CODE NO.
B1	OSCILLATOR VALVE	TB2 5/300
BU	P U AND SOCKET	
C1	D C BOX CAPACITOR 0.1μF 3400V	48 343 10/5100K
C2	2 FOIL MICA CAPACITOR R470 cF 1500V	48 461 10/470E
R1	RHEOSTAT 200 OHM 40W	88 300 45/A200E
R2	RHEOSTAT 1000 OHM 25W	88 300 44A/1K
R3	WIRE RESISTOR 6300 OHM 16W	88 300 33A/GK3
R4	ENAMELLED POTENTIOMETER 5000 OHM 40W	E198 AC/ A36A 5X
S1,S2,S3	COIL UNIT	E4 521 75
SK1	2 PIN WAFER SWITCH 10 AMP	
SK2	HOOK SWITCH	
V	FUSE 315 mA	
T1	PHILIPS TRANSFORMER 240/900-1400V 380VA	T1 810 09
T2	PHILIPS TRANSFORMER 240/6.3V	T1 700 07
T3	REGULATING TRANSFORMER 240/0-260V 520VA	
ZK1	COILING ELECTRODE	
BU2	PLUG AND SOCKET	

FIGURE 11.4.0

Base torsion test failure
Low or high lumens
Low or high watts
Poor base insulation - Meg ohm test
Poor life performance
Low gas pressure - gas-filled lamps
Flash failure on vacuum lamps.

11.4 High Frequency Coiling

One of the most useful tools for manufacturing and inspecting incandescent lamps of all types is the High Frequency Coil (sometimes called a Tesla coil). Figure 11.4.0 is a general schematic of such a coil. The use of this device is called "coiling."

Typical application of the high frequency coils are as follows:

11.4.1 Vacuum Measurements

When a lamp with approximately 10^{-3} Torr or less is coiled, there is no ionization and the bulb remains clear. This is referred to as a "hard" vacuum. Above 10^{-3} Torr the gas ionized starting with a pale color which becomes more vivid as the pressure rises. Above some pressure, the gas no longer ionizes but an arc is generated from bulb wall to the leads and filaments.

"Coiling" is used to inspect a quantity of vacuum lamps. Coiling is done in a dark booth. A fan is necessary for ventilation to remove ozone generated by the high frequency coil. The poor vaccum lamps are easily separated from the "hard" vaccum lamps. The air lamps or leakers are also obvious and easily separated. Several thousand miniature vacuum lamps can be thoroughly inspected in a short time.

"Coiling" is used to monitor the condition of heads on an exhaust machine. The color of the discharge in the bulb as it passes a high frequency coil indicates the pressure in the head. A head with a more vivid or heavier color means that the head leaks or the bulb leaks. Repeat condition is a sure indicator of a head problem.

"Coiling" can be used to inspect the vacuum and flush cycle on an exhaust machine. By using hand-held "coil" and walking around the machine and "coiling" each position. Conclusions can be reached regarding pump conditions, sweeps, leak recovery time, ultimate pressure in lamp, etc.

"Coiling" can be used to leak check glass vacuum systems. By moving the probe all over the glass surface, any leaks will show up as small, bright lights or stars. The light is actually an arc which occurs in the leak due to the pressure drop between outside air and inside low pressure (vacuum). The probe should not be held stationary for more than a few seconds because the arc from coils can puncture a thin piece of glass and cause a leak.

"Coiling" is not recommended for microminiature lamps because the energy from the coil can either destroy the filament or cause the lamp to go "gassy" by over-heating the bulb. Lamps below T1 3/4 are not usually "coiled." Microminiature lamps can be checked by gas current (use lamp as a Prianni tube) or read lamp current in air and then with the lamp immersed in liquid nitrogen The smaller the difference in current, the better the vacuum.

11.4.2 Outgassing Glass

When a lamp is pumped to a low pressure and then coiled, a blue discharge occurs which fades and stabilizes to some value. If the coil is removed and then returned, only the stabilized color is seen. It is evident that coiling has liberated some gas which is then removed from the lamp by the pumps.

It should be noted that the gas thus liberated cannot be liberated by mere heating of the walls to their softening point; gas can be attached to the walls in some such way that it can be liberated by the discharge but not by heating. Of course, the attachment may consist of chemical combination; it is possible that glass contains hydrogen chemically combined, probably as water. But it should be observed that the hydrogen liberated, if piled up on the glass, would form a layer at least 25 molecules deep. Since the potential driving the discharge

in these experiments was often as low as 50 volts, it is hardly to be expected that the electrons or ions could penetrate so far into the glass simply by virtue of the energy which they receive from the discharge. It seems easier to believe that a layer on the surface, subject to the action of these particles, is constantly renewed by diffusion from within.

Since it is necessary to remove the gases liberated, it is often desirable to "coil" the lamp at higher pressure (1-4 Torr) so that the liberated gas can be removed along with flush gas. The liberated gas is diluted by the flush gas so that residual gas is mostly flush gas.

11.4.3 Identification of Fill Gases

Argon, Nitrogen, Krypton, Xenon, Hydrogen, etc., are normally used in the manufacture of gas-filled incandescent lamps. When a gas-filled lamp is "coiled" the color of the discharge is an indicator of the fill-gas and purity of the fill gas. The following table shows the basic color when lamp is coiled.

For discharge in air:

Pressure Range	Discharge Phenomena
$10 - 10^{-1}$ Torr	Red or purple glow in the vacuum system, expanding to the full cross section of the tube as the pressure decreases;
$10^{-1} - 10^{-2}$ Torr	discharge continues, in addition green fluroescence on the inner glass wall in the vicinity of the high-frequency electrode outside;
$10^{-2} - 10^{-3}$ Torr	red glow reduced, at about 10^{-3} Torr only a green fluorescence on the inner wall is visible;
below 10^{-3} Torr	no visible glow.

The color of the discharge depends on the nature of the gas.

Color of glow discharge for various gases:

Air	red to purple
Ammonia	blue
Argon	blue
Helium	purple-red to yellow-pink
Hydrogen	blue
Mercury vapor	greenish blue

Neon	red
Nitrogen	red-purple
Oxygen	lemon-yellow with reddish core
Water vapor & hydrocarbons	white-blue, almost white, faint
Krypton	white - blue-white.

The color changes with gas purity depending on the contaminant and also the type of discharge from soft glow to direct arcing around the mount.

"Coiling" to measure fill quality of gas-filled lamps takes practice but can be quite accurate when done by a trained observer.

The Cyanogen Test requires some optics and electronic circuitry but an integral component is a high frequency coil and again the color or wave lengths of the discharge are analyzed to indicate the purity of the fill-gas. Cyanogen (CN) spectrum is altered by the presence of oxygen and water vapor. A reduction in a normal amount of CN is an indicator of a contaminated and short life lamp.

11.4.4 An Unextinguishable Flame

A continuous arc from a coil can be used to light a gas-air-oxygen burner. Some burner applications such as the blow hole burner for GLS stems and tipping fires for all lamps are a source of burner outage problems. A coiler can be mounted to continuously supply a "lite" for the burner when needed.

11.4.5 Leak Detector

The color and brilliance of the ionized gases increase with pressure in the range of 7.5 microns (1 Pa) up to about 3000 Pa (22.5 Torr). The luminous energy can be detected by a photocell. By calibrating the photocell circuitry, a precision leak detector can be set up for vacuum lamps.

11.5 Air Lamps

Air lamps are gross leakers which show up at light up or spark coiling. The following are the usual causes of air lamps.

1.	Cracked Bulb	Thermal shock or scratch on bulb
2.	Cracked Stem Press	Fault in stem making and/or stem annealing.
3.	Cracked Seal	Fault in sealing in or basing fires too hot.
4.	Lead Wire Leaks	(a) "Cold Press" Fault in stem-making (b) Leaks due to weak bond between glass and dumet indicated by dark red seal color - fault in stem-making.
5.	Cracked Tip	Fault in tipping off - more likely on vacuum lamps.
6.	Leaky seals on smoked or white lite lamps	Particles of coating material sealed into bulb and flare seal. Cause is bad neck cleaning or marking.

NOTE: The leak may be a "slow leak" which is not indicated by the high frequency coiling initially but can only be detected after a hold period of several hours or days.

7.	"Wings" on seals	Sealing-in fault. Glass is liable to crack causing a leak (especially if the wing is broken off with pliers or tweezers).
8.	Blown out tips	Tipping-off fault on pump.
9.	Hole in seal	Fault in sealing-in
10.	Broken exhaust stem	Handling - weak stem.

11.6 Flash Failure (Vacuum Lamps)

Causes: 1. A lamp will "flash-over" if there is air or a gas at low pressure in the lamp. This condition is present when there is a "slow leak" in the lamp caused by a glass crack (usually cracked tips) or by a press leak or wire leak.

2. A lamp is liable to flash-over if the aging of the filament has not been completed satisfactorily. The lamp must be run up to 120% rated volts unballasted and held at this voltage for 15 seconds. The lamp should coil "dead hard" after aging by the high frequency coil test.
3. Lead-in wires too close.
4. Clamping of the filament on mounting mill faulty.
5. Gettered filaments in stock for too long a time. (phosphorous has become acidic.)
6. Glass dust in lamp.

11.7 Judgement by High Frequency Coiling

11.7.1 Gas-Filled Lamps

The initial judgement of pumping and gas-filling quality is made after the lamps have been based and aged. All lamps are burned and tested with the high frequency coil. Phosphorous gettered lamps which show "yellow" on the coil after burning must be rejected. This is an indication of lack of phosphorous on the filament.

Lamps which show "POOR" on the coil: If all lamps of a batch show "Poor" on the coil the indication is that EITHER the pumping system is faulty (leak in the gas lines, P_2O_5 driers need changing, dirty pumping system, dirty gas lines, bad cylinder of gas, unwanted vapors in the system) OR the mounted stems/unmounted stems have been left standing too long before sealing-in/pumping. Stems contaminated by grease or dirt show the same on the high frequency coil.

If only SOME of the lamps of the batch show "POOR" on the high frequency coil this is an indication that isolated heads on the pump are faulty (very small leak in a rubber, head not closing properly, etc.). There may be in the same batch degrees of quality, varying from "GOOD" to "POOR" - this is an indication that a leaky lamp or open head on this pump not valved off by the Leak Detector has contaminated lamps before and after the leaky lamp or open head.

11.7.2 Vacuum Lamps

All lamps must be "dead-hard" when tested with the high frequency coil after ageing.

11.8 Judgement After One Hour's Burning at 120% Rated Volts

11.8.1 Gas-Filled Lamps

High Frequency Coiling; Appearance	This should be a very soft purple color. This molybdenum supports must be perfectly clean. Darkening of the supports 1 - 4 M/M from the filament is an indication of the presence of water vapor in the lamp. The degree of darkening indicates the extent of water vapor attack. Water vapor has a disastrous effect on the life of the lamp (it rapidly accelerates the evaporation of the filament).

11.8.2 Vacuum Lamps

High Frequency Coiling	The lamp must be "dead-hard."
Flash-over tests	(Test when the lamps are at room temperature). The lamps must not flash over when switched on at 120% rated volts.

11.9 Factors Which Determine the Life of a Lamp When Operating Under Normal Conditions and at Rated Volts

1. The correct filament (correct light output). Correctly mounted filament.
2, Pumping and gas filling quality.
3. Glass parts which will not crack during the lamp's burning.
4. Perfect glass to metal seal (in the press which will NOT CRACK OR LEAK.

11.9.1 Shock and Vibration Tests
(See Chapter 10 Lamp Performance)

11.9.2 Calculations of Rated Life
(See Chapter 10 Lamp Performance)

11.9.3 Calculation of ℓpw at Rated Life (Not Recommended for GLS Lamps)
(See Chapter 10 Lamp Performance)

11.10 Quality - Inspection and Control of Production Process

1. Quality is Built Into the Product
Faults cannot be rectified by inspection, but can be prevented by adequate and efficient control at every stage of manufacture. INSPECTION SHOULD PRODUCE A RUNNING COMMENTARY ON THE QUALITY so that corrective measure, if necessary, can be taken immediately, thus preventing rejects.
LAMP MATERIALS ARE EXPENSIVE
2. In order to achieve and maintain consistently good quality of the product other considerations must be taken into account:
   a. Cleanliness of machinery and equipment. General cleanliness of the factory (Good Housekeeping).
   b. Seeing that the machinery and mechanisms are regularly lubricated.
   c. Adequate and efficient machine maintenance. (Replacement of worn or burnt parts when necessary).
   d. WORKING TO INSTRUCTIONS AND LAMP SPECIFICIATIONS.
   e. Check to see that components or assemblies from preceding operations are satisfactory. For example: it is wasteful and inefficient to seal-in mounted stems when the batch is known to contain stems having faults (such as "no hole in press," burnt wires, leaky press. The batch should be 100% inspected and the stems with faults rejected.

Certain controls must be done regularly (Gas pressure measurements, burning lamps for 1 hour and assessing general lamp quality, photometry, base torsion testing, life testing). Such controls are done by a separate person who must report back to the supervisor IMMEDIATELY any feature which is out of control.

OPERATION		INSPECT AND CONTROL
Flange-making	Inspect	1. Shape
		2. End Glazing
		3. Chips or cracks
		4. Dimensions
	Control	Strain under Strain Viewer (Polariscope)
Stem-making	Inspect	1. Alignment
		2. Wires correct color and NOT burnt
		3. Leaky press
		4. Exhaust stem well blown out
		5. Hole in press
		6. Well blown out
		7. All dimensions
		8. Chips or cracks
		9. Correct leading-in wires
		10. Sheathing wire around fuse not cracked
		11. Ballotini filled correctly
	Control	Strain under Strain Viewer
		Strength of exhaust tube.
		ANNEALER
Mounting Mill	Inspect	1. Pigtails not shorting in stud
		2. Cracked stud.
		3. Filament not distorted
		4. Correct filament pinching-in
		5. Correct number of pigtails
		6. Even spacing of pigtails
		7. Pigtail eyes closed
		8. Correct filament-tension
		9. Lead tip spacing correct
		10. Dimensions
		11. Phosphorous dosing

	Control	1. Phosphorous dosing (within 1/2 hour after starting production and then continuously by checking phosphorous tint of lamps in the final test box)
		2. Phosphorous pot and Methylated Spirit dripper (control continuously)
		3. The correct rating of filament.
Sealing-in	Inspect	1. Cracks or chips
		2. Shape
		3. Neck forming
		4. Stamping and burning-in
		5. Dimensions
		6. No wings on seals
		7. No sharp seals
		8. No cracked presses
	Control	1. Heat distribution burners
		2. Sealing-in pins - free access of air through center of pins.
		3. Annealing burners
		4. Sealing pins all the same height and free to move easily
		5. Cradles and bridge pieces same height
		6. Neck moulds set correctly
		7. Neck mould burners.
Pumping	Inspect	Form, Length and shape of tips. (VERY IMPORTANT ON VACUUM LAMPS)
	Control	1. Leak Detector is operating satisfactorily.
		2. Oven temperature when "hot" pumping
		3. Each position with high frequency coil (when starting and regularly throughout the production period)

4. Check lamps from each head with high frequency coil regularly
5. Check gas cylinders. When a new cylinder is put in circuit check all connections with soapy water for leaks on the high pressure side.
6. Check P_2O_5 driers
7. Check oil reservoirs to valve plates.

<u>Basing</u> <u>Inspect</u>

1. Uncut wires
2. Badly soldered or unsoldered
3. Crooked bases
4. Basing cement not baked or over-baked
5. Solder down flange tube
6. Leading-in wires touching
7. Damaged bases.

<u>Control</u>

1. Check voltage and resistance settings
2. Check burners and check to see that basing cement is properly baked. Check color after baking - should be more brown than green.
3. Check to see that bases are not too hot when soldering
4. Check wire cutting, flexing and soldering.

NOTE: When using bases which require side solder, special attention is required - <u>keep flame away from the glass bulb neck.</u>

<u>AGEING</u>

A. <u>Gas-filled lamps</u> Gas-filled lamps are aged during the basing operation.

<u>Control</u>: 1. Check voltage and resistance settings on Control Panel

B. Vacuum Lamps

Vacuum lamps are aged on Ageing machine (to render the lamps "dead hard" on high frequency coil).

Control: 1. Check voltage and resistance settings on Control Panel

Control: 2. Check to see that all positions on the Ageing Machine are in good order and that lamps light up on every position.

Inspection and High Frequency Coiling

Gas-Filled Single Coil Lamps

1. In frame provided turn the tray of lamps so that they are base-up.
2. Inspect for:
   a. Uncut wires
   b. Bad soldering
   c. Cement on bases

Lamps showing these defects must be taken out of the tray and passed to the repair bench.

3. High-frequency Coil the lamps (leaky lamps must be removed). Phosphorous gettered lamps which show "yellow" on the coil should be noted.
4. Run the lamps up to 20% over rated voltage SLOWLY. NOTE: CHECK VOLTAGE
5. Run the lamps down to low voltage. Inspect filament formation. Any lamps which show "knocked filaments" or "distorted filaments" must be rejected. Lamps which show part of filament unlit must be rejected (caused by pigtails shorting in the stud).
6. Switch off
7. High-frequency coil the lamps. Leaky lamps must be removed (rejects). Phosphorous gettered lamps which show "yellow" on the coil should be removed (rejects).

If the lamps which initially showed "yellow on the coil show satisfactory on the second coiling they can pass. Lamps which do not light up must be inspected (broken filament - broken fuse - which are rejects). (Poor contact, wire not threaded, which are repairable).

8. RECORD REJECTS TRAY BY TRAY ON FORM PROVIDED. REJECT LAMPS MUST BE RETAINED UNTIL AFTER EXAMINATION. Gas-filled Coiled-coil lamps (this includes 40 - 100 white light lamps).
   Exactly the same procedure as for gas-filled single-coil lamps except for Point 5.
9. Run the lamps up to 20% over rated voltage SLOWLY and hold for 10 seconds.

NOTE: CHECK VOLTAGE. THE GAS-FILLING - PUMPING QUALITY IS ASSESSED BY THE HIGH FREQUENCY COIL AND ANY OBSERVED VARIATION FROM THE ACCEPTED STANDARDS MUST BE REPORTED IMMEDIATELY.

Inspection and High Frequency Coiling - After Ageing on Ageing Machine.

(B) VACUUM LAMPS

1. In Frame provided turn the tray of lamps so that they are base-up.
2. Inspect for:
   a. Uncut wires
   b. Bad soldering
   c. Cement on bases.

   Lamps showing these defects must be taken out of the tray and passed to the repair benches.
3. High Frequency coil the lamps. Leaky lamps must be removed (rejects).
   LAMPS WHICH ARE NOT DEAD HARD ON THE COIL MUST BE REMOVED AND PASSED BACK TO THE AGEING MACHINE FOR REAGEING.
4. RUN THE LAMPS UP TO 20% OVER RATED VOLTAGE SLOWLY AND ALLOW THE LAMPS TO BURN AT THIS VOLTAGE FOR 15 SECONDS.

   CHECK VOLTAGE.

5. RUN THE LAMPS DOWN TO LOW VOLTAGE.
   Inspect filament formation. Any lamps which show "knocked filaments" or distorted filaments show part of the filament unlit must be rejected (caused by pigtails shorting in the stud).
6. Switch off.
7. High Frequency - coil the lamps.
   Leaky lamps must be rejected.
8 RECORD REJECTS TRAY BY TRAY ON FORM PROVIDED. REJECTED LAMPS MUST BE RETAINED UNTIL AFTER EXAMINATION.

NOTE: THE RECORDING OF REJECTS, TRAY BY TRAY, GIVES A RUNNING ACCOUNT OF THE QUALITY PERFORMANCE OF THE GROUP AND RUNNING FAULTS QUICKLY HIGHLIGHTED SO THAT CORRECTIVE MEASURES CAN BE IMPLEMENTED IMMEDIATELY.

SECOND CONTROL

After manufacture, and before packing, each batch of lamps must pass the second quality control station. 10% of each batch are inspected and controlled for quality and if the sample contains more than the agreed level of faults a further 10% must be checked. If the faults are contained in the further sample at the same, or at a higher level, the whole batch must be 100% re-inspected. After re-inspection, the 10% control must be exercised.

(THE 10% MUST BE TAKEN FROM THE BATCH AT RANDOM)

RECORDS MUST BE KEPT OF EVERY BATCH TESTED. THIS GIVES A RUNNING ACCOUNT ON THIS SECOND CONTROL.

11.11 Independent Production Controls

PUMPING QUALITY

a. Gas-filled Clear and Pearl

6 lamps are taken from each group every hour. After High Frequency coiling the lamps are burned base up at 120% rated volts for 1 hour.

After burning the lamps are High Frequency coiled and the inside of the lamps carefully examined.

THE FILAMENT SUPPORTS MUST BE PERFECTLY CLEAN.

A darkening of the supports 1-5mm from the filament is an indication of the presence of water vapor in the lamp and the degree of darkening indicates the extent of water vapor. Judgement is made of the HIgh Frequency coiling before and after 1 hour's burning. The 6 lamps are inspected for all features (including dimensions).

Bases are torsion tested and measured for insulation.

b. Vacuum Lamps

6 lamps are taken from the group every hour. After High Frequency coiling the lamps are burned base up at 120% rated volts for 1 hour.

The lamps are inspected for all features (including dimensions).

Bases are torsion tested and measured for insulation.

FLASH TEST: (Switching the lamps on at 120% rated volts. Lamps must be in holders base up).

10% of lamps are taken at random for Flash Test. If "flash-overs" are found 100% of batch must be flash tested.

NOTE: The test is to switch on at 120% rated volts, NOT to run them up to maximum volts.

c. Whitelight Lamps

Same procedure as for Gas-filled, Clear and Pearl lamps.

In addition, take 6 lamps per hour and burn base down at 120% rated volts. There should be no black-streaking or darkening on the inside of the bulb (examine by breaking open one or two of the lamps).

d. Gas Pressure — A lamp is taken from each group every 4 hours and measured for gas pressure.

e. Photometry — 6 lamps are taken from each group every 4 hours and measured for light output and current. In addition, immediately after a change of filament rating, a Photometry and Current check is made.

11.12 Quality Control Organization and Functions

There are five major areas in which Quality Control operates, viz. a) M.I.D., b) Process Control, c) Final Inspection, d) Test and Measurements, and e) Customer Relations.

a. M.I.D. - The Material Inspection Department is usually under Quality Control. This phase of the operation concerns itself with the inspection and disposition of material incoming to the plant such as glass, lead wires, bases, coils, etc. In many cases, where previous history is satisfactory, the inspection is quite small and of a token nature.
   The function of this operation is to prevent non-standard or out-of-tolerance parts from getting into the manufacturing process and causing shrinkage or down time.

b. PROCESS CONTROL - This operation is sometimes under the Product Engineering group. It is quite important that it be done effectively. Such controls are extended to overhang, lead tip spacing, glass strain analysis, etc. It is quite obvious that proper controls on the process will result in reduced shrinkage and improved quality.

c. FINAL INSPECTION - This function of the Quality Control group assures that only acceptable quality is shipped from the plant. The sampling is usually in accordance with MIL-STD-105D and for incandescent lamps the acceptable quality level is 0.65%. In practice, it is better. Rejected lots are returned for re-inspection.
   Since incandescent lamps have a tendency to have some additional failures (air lamps) with time, the Quality Control group holds a small portion of the inspected production for thirty days as a check. This provides additional information as to the quality of lamps leaving the factory.

d. TESTS AND MEASUREMENTS - Quality Control is responsible for the performance of photometric, life and other environmental tests. Current and lumen ratings are taken and translated into wattage and ℓpw. Life tests, both accelerated (force) and normal are made, and results studied for possible improvements. In addition, drop tests, base strength tests, and other performance tests are made as required.

It is important that photometers be calibrated to precise standards and that voltages used are properly regulated.

e. CUSTOMER RELATIONS - The Quality Control group as part of its function periodically recalls lamps from field warehouses and makes an appraisal of lamps in the field. All important complaints and RRARs funnel through Quality Control for corrective action.

f. SUMMARY - A good and effective quality organization is essential to the success of the product and plant. It is the consumer's representative in the plant. However, quality in a product is achieved only through the combined efforts of all and an acceptance of the slogan "Quality is everybody's business."

11.13 Analysing the Data

One of the commonest problems facing the engineer is that of summarizing a number of experimental observations by picking out the important features of the data. Only then will it be possible to try and interpret the results. The simple methods of analysing data which are considered in this chapter are widely used and are often given the collective title "Descriptive Statistics."

It is important to realize from the outset that the observations are usually a sample from the set of all possible outcomes of the experiment (sometimes called the population). A sample is taken because it is too expensive and time-consuming to take all possible measurements. Statistics are based on the idea that the sample will be "typical" in some way and that it will enable us to make predictions about the whole population.

The data usually consists of a series of measurements on some feature of an experimental situation or on some property of an object. The phenomenon being investigated is usually called the variate.

11.13.1 Pictorial Methods

It is always a good idea to plot the data in as many different ways as possible, as much information can be obtained just by looking at the resulting graphs.

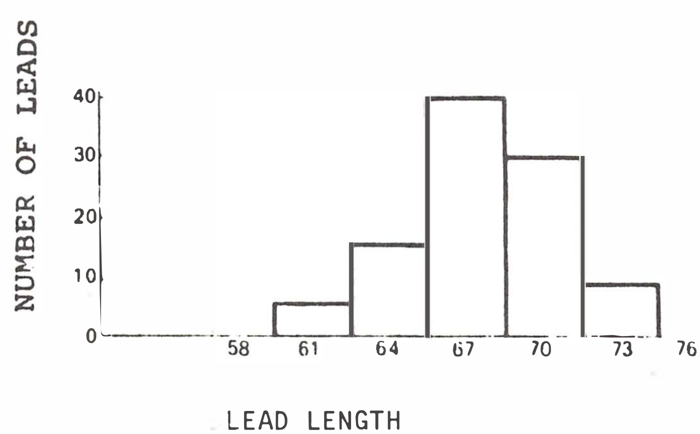
11.13.2 The Histogram

A histogram is a representation of a frequency distribution by means of rectangles whose widths represent class intervals and whose heights represent corresponding frequencies. It is best illustrated by an example:

Example I

The length of 100 lead wires were measured to the nearest mm and tabulated as follows:

Length		Number of Leads
60-62		6
63-65		15
66-68		40
69-71		30
72-74		9
	Total	100



Histogram of data - Example 1

11.13.3 How to Draw a Histogram

1. Allocate the observations to between five and twenty class intervals. In Example 1 (60-62) mm is a class interval.
2. The class mark is the midpoint of the class interval. All values within the interval are considered concentrated at the class mark.
3. Determine the number of observations in each interval.
4. Construct rectangles with centers at the class marks and areas proportional to the class frequencies. If all the rectangles have the same width then the heights are proportional to the class frequencies.

The choice of the class interval and hence the number of intervals depends on several considerations. If too many intervals are used then the histogram will oscillate wildly but if too few intervals are used then important features of the distribution may be overlooked. This means that some sort of compromise must be made. As the number of observations is increased the width of the class intervals can be decreased as there will be more observations in any particular interval.

QUALITY ASSURANCE OF INCANDESCENT LAMPS

Histogram shapes. Histograms come in all shapes and sizes. Some of the common shapes are illustrated below.

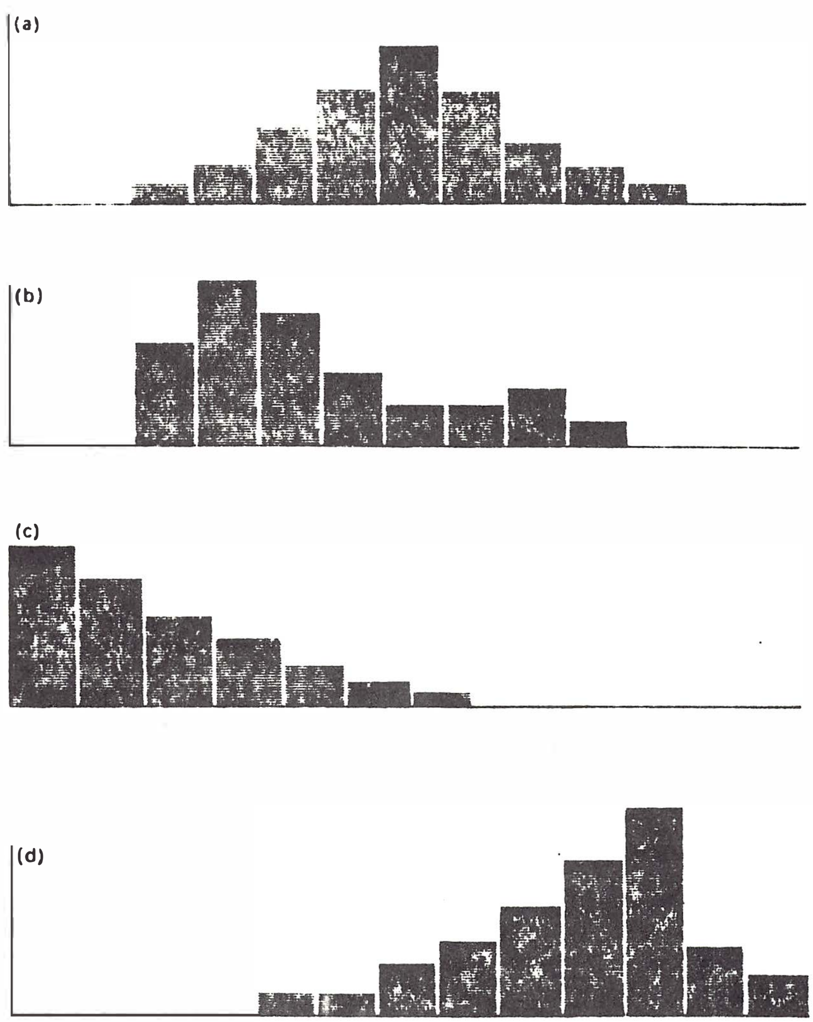
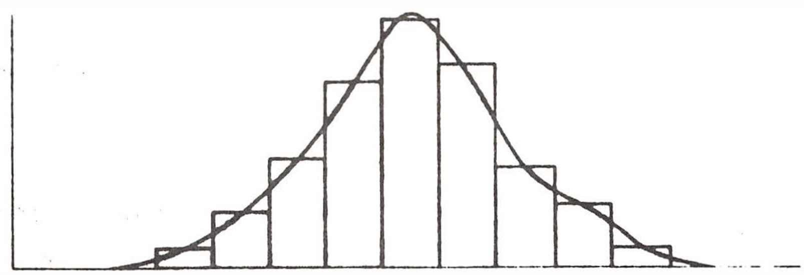


Figure 5 Various histograms
(a) symmetric or bell-shaped
(b) skewed to the right or positively skewed
(c) reverse *J*-shaped
(d) skewed to the left or negatively skewed

FREQUENCY CURVE

Where there are a large number of observations the histogram may be replaced with a smooth curve drawn through the midpoints of the tops of each box. Such a curve is called a frequency curve.



Frequency Curve

The above type of curve would be expected if number of failures at increasing life of incandescent lamps were plotted. The early failures due to defects would be to the left and long lives due to lower efficiency, superior filament wire, etc., would be to the right and rated or average life would be the mid-point.

Weibull, Normal Law, or other cumulative percentage distribution plots are also useful for visualizing statistical distribution data..

11.13.4 Arithmetical Methods

In addition to the graphical techniques, it is often useful to calculate some figures to summarize the data. Any quantity which is calculated from the data is called a statistic (to be distinguished from the subject statistics). Thus a statistic is a function of the measurements or observations.

Most simple statistics can be divided into two types: firstly quantites which are "typical" of the data and secondly, quantities which measure the variability of the data. The former are usually called measures of location and the latter are usually called measures of spread.

11.13.5 Measures of Location

There are three commonly used measures of location, of which the mean is by far the most important.

11.13.5.1 The Mean

Suppose that n measurements have been taken on the variate under investigation, and these are denoted by $x_1, x_2 \ldots, x_n$. The (arithmetic) mean of the observations is given by

$$\bar{x} = \frac{x_1 + x_2 \ . \ . \ . + x_n}{n}$$

In everyday language we say that $\bar{x}$ is the average of the observations.

EXAMPLE I The lives of 10 lamps are as follows: 500, 550 575, 625, 650, 700, 725, 750, 775, 825 hours. Find the average life.

$$\bar{x} = \frac{500+550+575+625+650+700+725+750+775+825}{10} = 667.5 \text{ hrs.}$$

Average lamp life = 667.5 hours.

EXAMPLE II Find the mean life of a group of 100 lamps with lives and frequency in the following table:

Number of Lamps	Lamp Life
10	500
30	625
40	700
10	750
10	860

$$\frac{(500\times10) + (625\times30) + (700 \times 40) + (750 \times 10) + (860 \times 10)}{100} = \bar{x}$$

$\bar{x}$ = 678.5 hours = mean life of the lamps.

11.13.5.2 The Median

The Median is occasionally used instead of the mean, particularly when the histogram of the observations is skewed. It is obtained by placing the observations in ascending order of magnitude and then picking out the middle observation. Thus half the observations are numerically greater than the median and half are smaller.

EXAMPLE:

The weight of twelve filaments selected at random from one group is:
9, 20, 11, 6, 10, 10, 14, 8, 9, 9, 12, 9 mg
This gives $\bar{x}$ 10.6 mg.

Rewriting the observations in ascending order of magnitude we have
6, 8, 9, 9, 9, 9, 10, 10, 11, 12, 14, 20, mg.
As there are an even number of observations the median is the average of the sixth and seventh values, namely nine and a half (9.5 mg). As eight of the observations are less than the sample mean, it could be argued that the median is "more typical " of the data. In Chapter 10, average or rated life was calculated several ways. The method where rated life is defined as the point were 50% of sample has failed is actually a calculation of the median life.

11.13.5.3 The Mode

This is the value of the variate which occurs with the greatest frequency. For discrete data the mode can easily be found by inspection. For continuous data the mode can be estimated by plotting the results in a histogram and finding the midpoint of the tallest box. Thus in example of lead length (11.11.2) the mode is 67 mm.

11.13.5.4 Comparison

As we have already remarked, the mean is by far the most important measure of location. When the distribution of results is roughly symmetric, the mean, mode and median will be very close together

anyway. But if the distribution is very skewed there may be a considerable difference between them and then it may be useful to find the mode and median as well as the mean.

11.13.5.5 Range

This is the difference between the largest and smallest observation. It can be very useful for comparing the variability in samples of equal size but is unfortunately affected by the number of observations; the more observations taken, the larger the range will be. So it is not a fixed characteristic of the population.

11.13.6 Variance and Standard Deviation

The sample variance S^2 of no observations, X_1, X_2. . . .X_n, is given by

$$S^2 = \frac{(X_1 - \bar{X})^2 + (X_2 - \bar{X})^2 + \ldots + (X_n - \bar{X})^2}{(n-1)}$$

$$= \sum_{i=1}^{n} \frac{(X_i - \bar{X})^2}{n-1}$$

The standard deviation s of the sample is obtained by taking the square root of the variance.

$$s = \sum_{i=1}^{n} \left[\frac{(X_i - \bar{X})^2}{n-1}\right]^{1/2}$$

The standard deviation is in the same units as the original measurements and for this reason it is preferred to the variance as a descriptive measure. However, it is often easier from a theoretical and computational point of view to work with variances. Thus the two measures are complementary.

In order to calculate a variance on a desk calculating machine, it is usually more convenient to rearrange the form as follows:

$$s^2 = \frac{\left[\left(\sum_{i=1}^{n} s_i^2\right) - n\bar{x}^2\right]}{(n-1)}$$

<u>EXAMPLE</u>:

Find the range, variance and standard deviation of the following 6 observations.

0.9, 1.3, 1.4, 1.2, 0.8, 1.0

Range = 1.4-0.8=0.6

$$\bar{x} = \frac{6.6}{6} = 1.1$$

$$\sum x^2 = (0.9)^2+(1.3)^2+(1.4)^2+(1.2)^2+(0.8)^2+(1.0)^2$$

$$\sum x^2 = 7.54$$

$$s^2 = \frac{(7.54 - 6(1.1)^2) = 0.056}{5} = 0.056$$

S = 0.237

11.13.7 Coefficient of Variation

We have seen that the standard deviation is expressed in the same units as the individual measurements. For some purposes it is much more useful to measure the spread in relative terms by dividing the standard deviation by the sample mean. The ratio is called the coefficient of variation.

$$\text{(coefficient of variation)} = \frac{S}{X}$$

For example a standard deviation of 10 may be insignificant if the average observation is around 10,000 but may be substantial if the average observation is around 100.

Another advantage of the coefficient of variation is that it is independent of the units in which the variate is measured, provided that the scales begin at zero. If every observation in a set of data is multiplied by the same constant, the mean and standard deviation will also be multiplied by this constant, so that their ratio will be unaffected. Thus the coefficient of variation of a set of length measurements, for example, would be the same whether measurements were made in centimeters or inches. However, this is not true, for example, for the centigrade and Fahrenheit scales of measuring temperature where the scales do not begin at zero.

11.13.8 Curve Fitting

11.13.9 Scatter Diagram

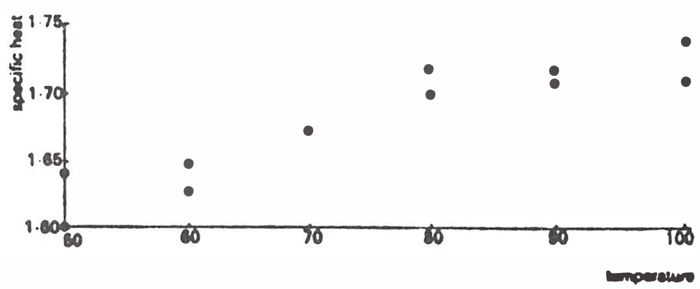
Suppose that n pairs of measurements, (X_1, Y_1), $X_2, Y_2)$, ..., (X_n, Y_n), are made on two variables x and y. The first step in the investigation is to plot the data on a scatter diagram in order to get a rough idea of the relationship (if any) between x and y.

EXAMPLE I

An experiment was set up to investigate the variation of the specific heat of a certain chemical with temperature. Two measurements of the specific heat were taken at each of a series of temperatures. The following results were obtained:

Temperature °C	*50*	*60*	*70*	*80*	*90*	*100*
Specific heat	1·60	1·63	1·67	1·70	1·71	1·71
	1·64	1·65	1·67	1·72	1·72	1·74

Plot the results on a scatter diagram.



It is often possible to see, by looking at the scatter diagram, that a smooth curve can be fitted to the data. In particular if a straight line can be fitted to the data then we say that a linear relationship exists between the two variables. Otherwise the relationship is non-linear.

Situations sometimes occur, particularly in physical and chemistry, in which there is an exact functional relationship between the two variables and in addition the measurement error is very small. In such a case it will usually be sufficiently accurate to draw a smooth curve through the observed points by eye. Here there is very little experimental uncertainty and no statistical analysis is really required.

However, most situations are not so clear cut as this, and then a more systematic method is required to find the relationship between the two variables. In the first part of this Section we will discuss

the situation where the values of one of the variables are determined by the experimenter. This is called the controlled, independent or regressor variable. The resulting value of the second variable depends on the selected value of the controlled variable. Therefore, the second variable is called the dependent or response variable. However, the problem is usually complicated by the fact that the dependent variable is subject to a certain amount of experimental variation or scatter.

Thus, in Example 1, the temperature is the controlled variable and the specific heat is the dependent variable. At a fixed temperature, the two observations on the specific heat vary somewhat. Nevertheless, it can be seen that the average value of the specific heat increases with the temperature.

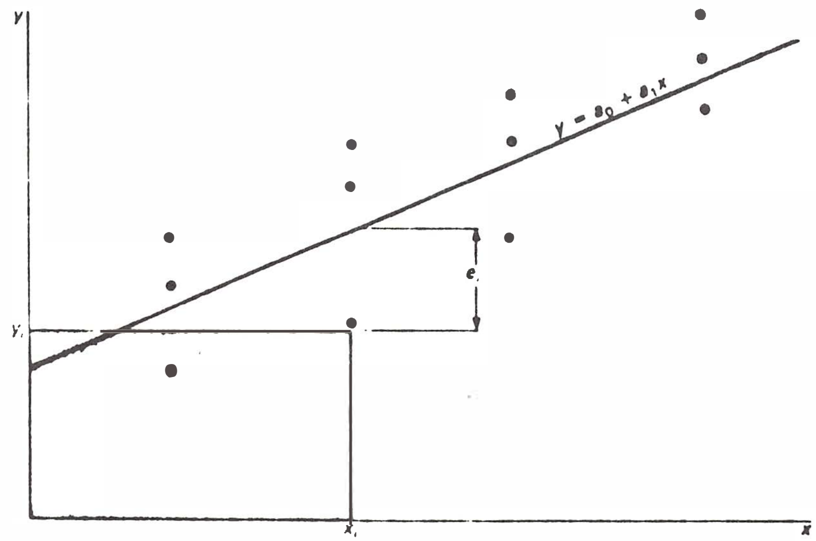
The problem now is to fit a line or curve to the data in order to predict the mean value of the dependent variable for a given value of the controlled variable. If the dependent variable is denoted by y and the controlled variable by x, this curve is called the regression curve, or line, of y on x.

We will begin by considering the problem of fitting a straight line to n pairs of measurements, $(x_1 y_1), \ldots., x_n y_n)$, where the y_i are subject to scatter but the x are not. A straight line can be represented by the equation:

$$y = a_o + a_1 x.$$

The task is find estimates of a_o and a_1 such that the line gives a good fit to the data. One way of doing this is by the "method of lease squares." At any point x_i the corresponding point on the line is given by $a_o + a_1 s_i$, so the difference between the observed value of y and the predicted value is given by

$$e_i = y_i - (a_o + a_1 x_i).$$



The least squares estimates of a_o and a_1 are obtained by choosing the values which minimize the sum of squares of these deviations. The sum of the squared deviations is given by

$$S = \sum_{i=1} e_i^2$$

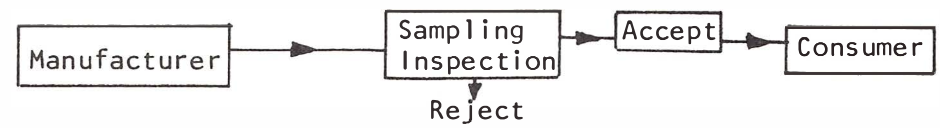
$$= \sum_{i=1} \left[Y_i - (a_o + a_1 x_i) \right]^2$$

At this point, the mathematics are becoming a task. With modern hand calculators, the formula for the curve can be arrived at easily. Generally, the curve for lamp data are power curves $y = b\, x^m$, log curves $y = g + \ell n x$ or exponential curves $y = b\, e^{mx}$. Programmable hand calculators like T1-59 or T1-52 have such programs and will also calculate the confidence factor which for a perfect fit would be 1.000.

11.14 Acceptance Sampling

Any manufacturing process will inevitably produce some defective items. The manufactured items will often be supplied by the manufacturer

to the consumer in batches or lots, which may be examined by the manufacturer before shipment or by the consumer before acceptance. The inspection often consists of drawing a sample from each batch and then deciding whether to accept or reject the batch on the evidence provided by the sample. A variety of sampling schemes exist; the more important of these will be described.



Acceptance Sampling

A simple type of sampling scheme is one in which a single sample is taken and the batch is accepted if there are not more than a certain number of defective items. For example, we could take a sample size 100 from each batch and reject the batch if there is more than one defective item. Otherwise the batch is accepted. Acceptance sampling is used when the cost of inspecting an item is such that it is uneconomic to look at every item in a batch. For example, it must be used in the case where the manufactured item is destroyed by the inspection technique. In contrast, in precision engineering it is more common to inspect every item, in which case there are few statistical problems and most of the following remarks do not apply.

When a batch is rejected by a sampling scheme, it may be returned to the manufacturer, it may be purchased at a lower price or it may even be destroyed. Alternatively rejected batches may be subjected to 100% inspection so that all defective items in the batch are replaced by good items.

Acceptance sampling plans can be divided into two classes. If the items in a sample are classed simply as "good" or "defective" then the sampling scheme is said to be sampling by attributes. This qualitative approach contrasts with sampling by variables, in which a quantitative measurement is involved. In other words an attribute scheme does not say how good or how defective an item is. Sometimes this is inevitable. For example, a light bulb will either work or it will not work. There is no in-between state and we must use sampling by attributes.

We shall concentrate our attention on attribute sampling schemes. Fortunately, many of the general principles involved also apply to sampling by variables.

11.5 Classification of Defects and Defectives

Method of Classifying Defects

A classification of defects is the enumeration of possible defects of the unit of product classified according to their seriousness. A defect is any nonconformance of the unit of product with specified requirements. Defects will normally be grouped into one or more of the following classes; however, defects may be grouped into other classes, or into subclasses within these classes.

Vital Defect

A vital defect is a defect that judgement and experience indicate is likely to result in hazardous or unsafe conditions for individuals using, maintaining, or depending upon the product; or a defect that judgement and experience indicate is likely to prevent performance of the tactical function of a major end item.

Major Defect

A major defect is a defect, other than critical, that is likely to result in failure, or to reduce materially the usability of the unit of product for its intended purpose.

Minor Defect

A minor defect is a defect that is not likely to reduce materially the usability of the unit of product for its intended purpose, or is a departure from established standards having little bearing on the effective use or operation of the unit.

11.6 Percent Defective and Defects Per Hundred Units

Expression of Nonconformance

The extent of nonconformance of product shall be expressed either in terms of percent defective or in terms of defects per hundred units.

Percent Defective

The percent defective of any given quantity of units of product is one hundred times the number of defective units of product contained therein divided by the total number of units of product, i.e.:

$$\text{Percent defective} = \frac{\text{Number of defectives}}{\text{Number of units inspected}} \times 100$$

Defects per Hundred Units

The number of defects per hundred units of any given quantity of units of product is one hundred times the number of defects contained therein (one or more defects being possible in any unit of product) divided by the total number of units of product, i.e.:

$$\text{Defects per hundred units} = \frac{\text{Number of defects}}{\text{Number of units inspected}} \times 100$$

11.15 Acceptable Quality Level (AQL)

Use

The AQL, together with the Sample Size Code Letter, is used for indexing the sampling plans provided herein.

Definition

The AQL is the maximum percent defective (or the maximum number of defects per hundred units) that, for purposes of sampling inspection, can be considered satisfactory as a process average.

Limitation

The designation of an AQL shall not imply that the supplier has the right to supply knowingly any defective unit of product.

Specifying AQLs

The AQL to be used will be designated in the contract or by the responsible authority. Different AQLs may be designated for groups of defects considered collectively, or for individual defects. An AQL for a group of defects may be designated in addition to AQLs for individual defects, or subgroups, within that group. AQL values of 10.0 or less may be expressed either in percent defective or in defects per hundred units; those over 10.0 shall be expressed in defects per hundred units only.

Preferred AQLs

The values of AQLs given in these tables are known as preferred AQLs. If for any product, an AQL be designated other than a preferred AQL, these tables are not applicable.

11.16 Submission of Product

Lot or Batch

The term lot or batch shall mean "inspection lot" or "inspection batch," i.e., a collection of units of product from which a sample is to be drawn and inspected to determine conformance with the acceptability criteria, and may differ from a collection of units designated as a lot or batch for other purposes (e.g., production, shipment. etc.)

Formation of Lots or Batches

The product shall be assembled into identifiable lots, sublots, batches, or in such other manner as may be prescribed. Each lot or batch shall, as far as is practicable, consist of units or product of a single type, grade, class, size, and composition, manufactured under essentially the same time.

Lot or Batch Size

The lot or batch size is the number of units of product in a lot or batch.

11.17 Acceptance and Rejection

Acceptability of Lots or Batches

Acceptability of a lot or batch will be determined by the use of a sampling plan or plans associated with the designated AQL or AQLs.

Defective Units

The right is reserved to reject any unit of product found defective during inspection whether that unit of product forms part of a sample or not, and whether the lot or batch as a whole is accepted or rejected. Rejected units may be repaired or corrected and resubmitted for inspection with the approval of, and in the manner specified by, the responsible authority.

Special Reservation for Critical Defects

The supplier may be required at the discretion of the responsible authority to inspect every unit of the lot or batch for critical defects. The right is reserved to inspect every unit submitted by the supplier for critical defects, and to reject the lot or batch immediately, when a critical defect is found. The right is reserved also to sample, for critical defects, every lot or batch submitted by the supplier and to reject any lot or batch if a sample drawn therefrom is found to contain one or more critical defects.

Resubmitted Lots or Batches

Lots of batches found unacceptable shall be resubmitted for reinspection only after all units are re-examined or retested and all defective units are removed or defects corrected. The responsible authority shall determine whether normal or tightened inspection shall be used, and whether reinspection shall include all types or classes of defects or for the particular types or classes of defects which caused initial rejection.

11.18 Drawing of Samples

Sample

A sample consists of one or more units of product drawn from a lot or batch, the units of the sample being selected at random without regard to their quality. The number of units of product in the sample is the sample size.

Representative Sampling

When appropriate, the number of units in the sample shall be selected in proportion to the size of sublots or subbatches, or parts of the lot or batch, identified by some rational criterion. When representative sampling is used, the units from each part of the lot or batch shall be selected at random.

Time of Sampling

Samples may be drawn after all the units comprising the lot or batch have been assembled, or samples may be drawn during assembly of the lot or batch.

Double or Multiple Sampling

When double or multiple sampling is to be used, each sample shall be selected over the entire lot or batch.

11.19 Defect and Shrinkage Symbols for Incandescent Lamps

The following is a list of lamp defects. The letter preceding the number defines whether the defect is VITAL, MAJOR or MINOR as defined in 11.16

D - VITAL DEFECT

C - MAJOR DEFECT

B - MINOR DEFECT

100-199 Atmosphere

101 - Arc
D 103 - Air Lamp
- A - Glow Test
- B - Burning Test

D 104 - Lamp Gassy
D 105 - Lamp not flashed
D 106 - No gas or Wrong gas present in lamp

C 123 - Glow persists
C 150 - Discoloration blue
B 151 - Discoloration black
- A - Non-Progressive

B 152 - Discoloration brown
"A" Phosphorous Getter
C 153 - Discoloration black progressive
- A - Sooty clamps or supports
- B - Black bulb

200-299 Filament

D 200 - Filament broken
D 201 - Filament missing

202 - Filament fragile
D 204 - Filament burned out
C 210 - Filament interlocked
C 220 - Filament joint defective
- A - Scissors Clamp
- B - Tight or loose

C 221 - Filament out of support or pigtail
D 222 - Filament out of joint
C 223 - Filament tension too high

224 - Minor coil missing
C 227 - Filament joint hot
C 230 - Filament irregular
- A - Loose
- B - Loops too close
- C - Filament too close to lead wire
- D - Kink or curl
- E - Irregular patch of coil
- F - Foreign material in coil

B 231 - Filament tilted
C 232 - Slipover or Minor coil not properly attached

200 - 299 Filament

C 233 - Filament wrong
    A - Mixed filaments
C 235 - Gettering poor
    A - Getter missing
    B - Getter poorly applied
    C - Wrong getter
D 270 - Extra Filament

300 - 399 Lead Wires

D 300 - Lead wire broken or missing
    A - Outer lead wire
    B - Press lead wire
    C - Inner lead wire
    D - Joint lead wire
305 - Inner leads shorted
    (Series Burning)
309 - Lead wire size wrong
C 310 - Lead wires short-circuited
C 311 - Lead wires in contact
    with base skirt
C 312 - Lead wires too close
    A - Outer lead wires
    B - Press lead wires
    C - Inner lead wires
C 313 - Lead wires too close to
    support
D 320 - Lead wire not soldered
    A - Eyelet
    B - Shell
    C - Shell in lamps not
        soldered by design
C 321 - Lead wire out of tie wire
    A - Tie wire missing
    B - Lead wire out of
        tie wire
E 322 Lead wire not cut
    A - Eyelet
    B - Shell
B 330 - Lead wire distorted
C 332 - Lead wires burned or corroded
    A - Outer lead wire
    B - Press lead wire
    C - Inner lead wire
D 340 - Lead wire not welded
    A - Eyelet
    B - Shell

300 - 399 Lead Wires

D 341 - Inverted lead wire
D 343 - Press lead wire exposed
B 350 - Dirty Mount
C 353 - Lead wire insulation omitted

C 360 - Lead wire in poor contact
    base shell
D 370 - Extra lead wire
D 390 - Fuse Wire Defective

400 - 499 Supports

C 400 - Disc support defective
C 401 - Support missing

C 402 - Support burned or oxidized

D 410 - Supports short-circuited
C 412 - Supports too close
C 413 - Support touches bulb

C 420 - Support loose or broken
B 421 - Support inserted ,correctly
B 430 - Support bent
    A - Bumped
    B - Bent
C 431 - Support poorly shaped
    A - Hook or Pigtail
        missing
    B - Hook or Pigtail poorly
        shaped
470 - Extra Support

500 - 599 Bulbs

D 500 - Bulb Broken
A - Neck or shoulder
B - Side
C - Bowl
AR - Ring off at base line
D 502 - Bulb Cracked
A - Neck or shoulder
B - Side
C - Bowl
D 503 - Lamp seal leaks
A - Crack
B - Hole in seal or imperfect sealing in
D 513 - Lamp not tipped
D 515 - Machine stuck
D 525 - Lamp seal poor
A - Stuck seal
B - Cullet not cut off
C - Mount not down in pin
D - Cullet cracked off leaving rough edge
E - Fine
B 534 - Bulb shape poor
A - Flat top or side
B - Indentations or Protuberances
C 537 - Bulb strained
A - Neck
B - Side
C - Top
C 540 - Bulb Wrong

C 541 - Light center wrong
B 543 - Overall length wrong
A - Too long
B - Too short
B 545 - Base cement exposed
C 546 - Lamp seal shoulder wrong
B 547 - Lamp seal shoulder distorted

500 - 599 Bulbs

B 550 - Bulb dirty
B 554 - Bulb blemished
(A - Cord or creases
(B - Scratches or
(scuffing
B (C - Blisters or stones
(D - Mold rings or
(twists in neck

B 556 - Material loose

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600 - 699 Mount Glass

D 600 - Stem tube or flange broken
D 601 - Stem press broken
C 602 - Stem tube or flange cracked
603 - Defective Mount Weld

D 604 - Arbor broken
C 605 - Arbor cracked or chipped

B 606 - Button cracked
C 607 - Bead cracked or chipped

C 608 - Stem press cracked
609 Tip broken
C 610 - Tip cracked

611 - Disc Loose (Metal)
D 612 - Exhaust tube broken
A - At press
B - Away from press
B 613 - Disc defective
C 614 - Disc tilted
D 615 - Exhaust tube closed
A - Orifice not blown thru press
B - Closed in glasing
616 - Stem parts missing
A - Exhaust tube
B - Arbor
C - Lead wires
C 617 - Lead knot exposed
618 - Cut out failure
619 - Improper cut out failure
D 620 - Stem press leaks

600 - 699 Mount Glass

B 621 - Mount eccentric
- A - Arbor & stem tube not concentric
- B - Mount not concentric with bulb
- C - Filament & stem tube not concentric with each other

C 624 - Arbor shank (metal) defective

630 - Tip poor shape
- A - Weak
- B - Sucked in
- C - Blown out

B 631 - Button poor

C 632 - Tip long
- A - Stringy
- B - Too long

633 - Stem press poor shape

634 - Tip Long (Lumiline)

D 635 - Bead faulty
- A - Poorly melted or discolored
- B - Too large or too small
- C - Loose

636 - Flange Poor
- A - Irregular or cracked
- B - Rotted cold

B 640 - Mount high or low

645 - Stem tubing poor
- A - Large or small
- B - Thick or thin wall
- C - Cracked

648 - Exhaust tube crooked
- A - Bent
- B - Not concentric

B 651 - Button discolored

B 652 - Stem press discolored

653 - Metal in stem tube

B 654 - Cement in stem tube

B 655 - Stem tube dirty

C 657 - Arbor orifice defective
- A - Too small
- B - Closed

700 - 799 Bases

D 700 - Base Inoperative

B 701 - Base damaged
- A - Split or punctured
- B - Eyelet or pin loose
- C - Out of round or crushed
- D - Threads distorted
- E - Base insulation broken

D 703 - Lamp inoperative cause unknown

D 704 - Solder in excess

C 709 - Short circuit or arc between contacts

E 710 - Base short-circuited

E 711 - Base loose

C 712 - Base cement deficient

C 713 - Base turned

714 - Base torn

B 721 - Soldering poor
- A - Eyelet
- B - Shell

B 723 - Bulb eccentric or base crooked

D 724 - Soldering wrong

C 740 - Base wrong

C 741 - T10 base clip position wrong

B 750 - Base dirty

B 741 - Base tarnished

---

800 - 899 Finish

C 801 - Marking Missing

D 803 - Lamp missing

B 830 - Marking poor

B 831 - Marking misplaced

B 832 - Diffusing Coating poor

C 834 - Diffusing coating improperly located

B 835 - Frosting burned clear

C 840 - Marking wrong

11.20 Notes on Shrinkage Classifications

104 Gassy Lamp	Evidenced by glow test, or by blue glow when lamp is lighted. Gassy lamps caused by oil or other foreign material in lamp will be included under defect 104.
105 Lamp not flashed	Lamps which burn out due to improper flashing will be included in this defect. This may be due to poor contact in flashing, wrong setting of rheostat, uncut lead wires short-circuiting the lamps during part of flashing.
106 No gas or wrong gas	Gas-filled lamps having excessively low gas pressure will be included under this defect.
204 Filament burned out	Where cause of burnout can be located, such as cracked bulb, press, or stem tube, or leaky tip, classify the shrinkage under defect causing burnout.
233 Filament wrong	Includes mixed filaments, coils, or mounts, but does not include mixed lamps, which are classified under 840.
300 Lead wire broken	In lamps with broken lead wires caused by the press lead not being covered by the glass will be classified under defect 343 - Press Lead Exposed.
312 Lead wires too close	Lead wires too close to the exhaust tube orifice, which may cause a cracked stem press will be classified under 312.
330 Lead wire distorted	Bumped mounts in which the lead wires are out position will be included in this defect.
332 Lead wires burned or corroded off	Lead wires burned off or corroded off will be classified under defect 300 - Lead Wire Broken.
343 Press lead exposed	See note under defect 300 Lead Wire Broken
430 Support bent	Bumped mounts in which the supports are bent out of position, but not the lead wires will be classified under this defect.
431 Support poorly shaped	Failure to form a hook or poorly formed hooks or pigtails will be included under defect 431. Broken hooks or pigtails will be included under defect 420 - Support Broken.

500 Bulb Broken	A bulb cracked or broken with some of glass out of position. Includes bulbs or lamps.
513 Lamp not tipped	Includes lamps pulled out of exhaust rubbers, or partially tipped.
556 Material loose	Pieces of glass loose or fused to the bulb larger than 50 sq. mm. will be included under defect 502. Less than 50 sq. mm. classify under defect 556.
600 Stem tube or flange broken	When stem tube cracks and allows a press lead to be exposed or leaves a hole in stem shoulder, classify under defect 645 - Stem Tubing Poor.

11.21 Sampling Procedures and Tables

MIL-STD-105D is universally accepted as a sampling standard for incandescent lamps.

Symbols and Notations

Symbols and notes used in this guide are as follows:

Ac	Acceptance number
AOQ	Average Outgoing Quality
AOQL	Average Outgoing Quality Limit
AQL	Acceptable Quality Level
	Consumer's risk
c	Acceptance number
DPU	Defects per hundred units
LQ	Limiting Quality
N	Lot size
n	Sample size
Pa	Probability of acceptance
PD	Percent defective
Re	Rejection number

When AQL's are specified for major and minor defectives, the following rules shall govern: A sample unit containing one or more major defects shall be classified a minor defective; a sample unit containing one or more major defects and one or more minor defects shall be classified (scored) as a major defective and a minor defective.

EXAMPLE

Given: Major AQL = 2.5 PD

Minor AQL = 4.0 PD

A sample unit was found to contain a major defect (broken weld) and a minor defect (paint run).

This sample unit shall be scored once as a major defective and once as a minor defective.

Sampling Plan

A sampling plan indicates the number of units of product from each lot or batch which are to be inspected (sample size or series of sample sizes) and the criteria for determining the acceptability of the lot or batch (acceptance and rejection numbers).

Inspection Level

The inspection level determines the relationship between the lot of batch size and the sample size. Unless otherwise specified, Inspection Level II will be used. However, Inspection Level I may be specified when less discrimination is needed, or Level III may be specified for greater discrimination.

Code Letters

Sample sizes are designated by code letters. Table I shall be used to find the applicable code letter for the particular lot or batch size and the prescribed inspection level.

Single Sampling Plan

The number of sample units inspected shall be equal to the sample size given by the plan. If the number of defectives found in the sample is equal to or less than the acceptance number, the lot or batch shall be considered acceptable. If the number of defectives is equal to or greater than the rejection number, the lot or batch shall be rejected.

Double Sampling Plan

The number of sample units inspected shall be equal to the first sample size given by the plan. If the number of defectives found in the first sample is equal to or less than the first acceptance number,

the lot or batch shall be considered acceptable. If the number of defectives found in the first sample is equal to or greater than the first rejection number, the lot or batch shall be rejected. If the number of defectives found in the first sample is between the first acceptance and rejection numbers, a second sample of the size given by the plan shall be inspected. The number of defectives found in the first and second samples shall be accumulated. If the cumulative number of defectives is equal to or less than the second acceptance number, the lot or batch shall be considered acceptable. If the cumulative number of defectives is equal to or greater than the second rejection number, the lot or batch shall be rejected.

The choice of the level of inspection depends on how close the estimated process average is to the AQL. Thus the scheme adopts the sensible approach of taking into account the quality of recent batches. If the production line turns out a bad batch then it is sensible to take larger samples than usual. On the other hand, if the process has been producing good batches for a long period then reduced sampling can be employed. The sampling scheme is chosen in such a way that the producer's risk is much smaller for large lots than for small lots. The reason for this is that it is much more serious to reject a large batch when it is "good" than it is reject a small batch.

The following is a copy of the double sampling inspection system from a GLS lamp plant. Note that the AQL varies considerably for Vitals, Majors and Minors. It is common to design inspection report work sheets for specific applications and sampling plans.

DOUBLE SAMPLING INSPECTION SYSTEM

1. A double Sampling Inspection System according to Mil. Std. 105D is applied to the finished product.
2. Remove from the pallets in the LOT the number of cases necessary to inspect the required sample size. Choose as random a sample as possible. Do NOT inspect more than 50 lamps from any one case.
3. Record the Tote Production Code from the Tote ticket.

TABLE I -- SAMPLE SIZE CODE LETTERS

LOT OR BATCH SIZE			GENERAL INSPECTION LEVELS		
			I	II	III
2	to	8	A	A	B
9	to	15	A	B	C
16	to	25	B	C	D
26	to	50	C	D	E
51	to	90	C	E	F
91	to	150	D	F	G
151	to	280	E	G	H
281	to	500	F	H	J
501	to	1200	G	J	K
1201	to	3200	H	K	L
3201	to	10000	J	L	M
10001	to	35000	K	M	N
35001	to	150000	L	N	P
150001	to	500000	M	P	Q
500001	and	over	N	Q	R

SINGLE NORMAL

TABLE II-A—Single sampling plans for normal inspection (Master table)

Sample size code letter	Sample size	0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
		Acceptable Quality Levels (normal inspection)																									
		Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↓	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31
B	3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45
C	5	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑
D	8	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑	↑
E	13	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	30 31	44 45	↑	↑	↑
F	20	↓	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑
G	32	↓	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑
H	50	↓	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑
J	80	↓	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑
K	125	↓	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
L	200	↓	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
M	315	↓	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
N	500	↓	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
P	800	↓	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Q	1250	0 1	↑	↓	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
R	2000	↑	↑	1 2	2 3	3 4	5 6	7 8	10 11	14 15	21 22	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑

↓ = Use first sampling plan below arrow. If sample size equals, or exceeds, lot or batch size, do 100 percent inspection.

↑ = Use first sampling plan above arrow

Ac = Acceptance number

Re = Rejection number

TABLE III-A—Double sampling plans for normal inspection (Master table)

Sample size code letter	Sample	Sample size	Cumulative sample size	0.010	0.015	0.025	0.040	0.065	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	10	15	25	40	65	100	150	250	400	650	1000
				Acceptable Quality Levels (normal inspection)																									
				Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re	Ac Re
A				↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	•	↓	↓	•	•	•	•	•	•	•	•	•
B	First	2	2	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	17 22	25 31
	Second	2	4																	1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27	37 38	56 57
C	First	3	3	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	17 22	25 31	↑
	Second	3	6																1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27	37 38	56 57	
D	First	5	5	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	17 22	25 31	↑	↑
	Second	5	10															1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27	37 38	56 57		
E	First	8	8	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	17 22	25 31	↑	↑	↑
	Second	8	16														1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27	37 38	56 57			
F	First	13	13	↓	↓	↓	↓	↓	↓	↓	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	↑	↑	↑	↑	↑	↑
	Second	13	26													1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27						
G	First	20	20	↓	↓	↓	↓	↓	↓	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	↑	↑	↑	↑	↑	↑	↑
	Second	20	40												1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27							
H	First	32	32	↓	↓	↓	↓	↓	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	↑	↑	↑	↑	↑	↑	↑	↑
	Second	32	64											1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27								
J	First	50	50	↓	↓	↓	↓	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	↑	↑	↑	↑	↑	↑	↑	↑	↑
	Second	50	100										1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27									
K	First	80	80	↓	↓	↓	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
	Second	80	160									1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27										
L	First	125	125	↓	↓	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
	Second	125	250								1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27											
M	First	200	200	↓	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
	Second	200	400							1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27												
N	First	315	315	↓	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
	Second	315	630						1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27													
P	First	500	500	↓	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
	Second	500	1000					1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27														
Q	First	800	800	•	↑	↓	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
	Second	800	1600				1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27															
R	First	1250	1250	↑	↑	0 2	0 3	1 4	2 5	3 7	5 9	7 11	11 16	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
	Second	1250	2500			1 2	3 4	4 5	6 7	8 9	12 13	18 19	26 27																

↓ = Use first sampling plan below arrow. If sample size equals or exceeds lot or batch size, do 100 percent inspection.

↑ = Use first sampling plan above arrow.

Ac = Acceptance number

Re = Rejection number

• = Use corresponding single sampling plan (or alternatively, use double sampling plan below, where available).

DOUBLE NORMAL

4. Inspect the required lamps for Vital, Major, and Minor defects as defined in Section 11.19.
5. Record in the spaces provided the number of lamps inspected from each case. When the TOTAL sample size has been inspected, circle the sample size number of the Packed Stock Inspection Worksheet.
6. According to the inspection results of the first sample, the LOT will be either ACCEPTED, REJECTED, OR SUBMITTED TO A SECOND SAMPLE INSPECTION.
7. When it becomes necessary to inspect a second sample, the results of this inspection will dictate the ACCEPTANCE OR REJECTION of the LOT.
8. All rejected LOTS will be 100% reworked and resubmitted to this sampling plan.

Lot Size	Sample Size	Vital 0.65 AQL		Major 1.5 AQL		Minor 4.0 AQL	
		AC	RE	AC	RE	AC	RE
1,201 - 3,200	n_1 - 80	0	3	2	5	5	9
	n_2 - 80	3	4	6	7	12	13
3,201 - 10,000	n_1 - 125	1	4	3	7	7	11
	n_2 - 125	4	5	8	9	18	19
10,001 - 35,000	n_1 - 200	2	5	5	9	11	16
	n_2 - 200	6	7	12	13	26	27

n_1 = First Sample

n_2 = Second Sample

11.23 Reference for Additional In-Depth Information

1. Guide for Use of Mil-STD-105D available from GSA Federal Supply Service, Washington, D.C. 20407.

2. American National Standard Sampling Procedures and Tables for Inspection by Attributes available from American National Standards Institute, Inc. - ANSI - 21.4 - 1971.

3. Incandescent Lamps by W. G. Matheson, GTE Sylvania, Danvers, Mass. 01923 - Chapter 18.

4. GTE Quality Control Manuals available from Quality Manager, GTE Sylvania, Danvers, Mass. 01923.